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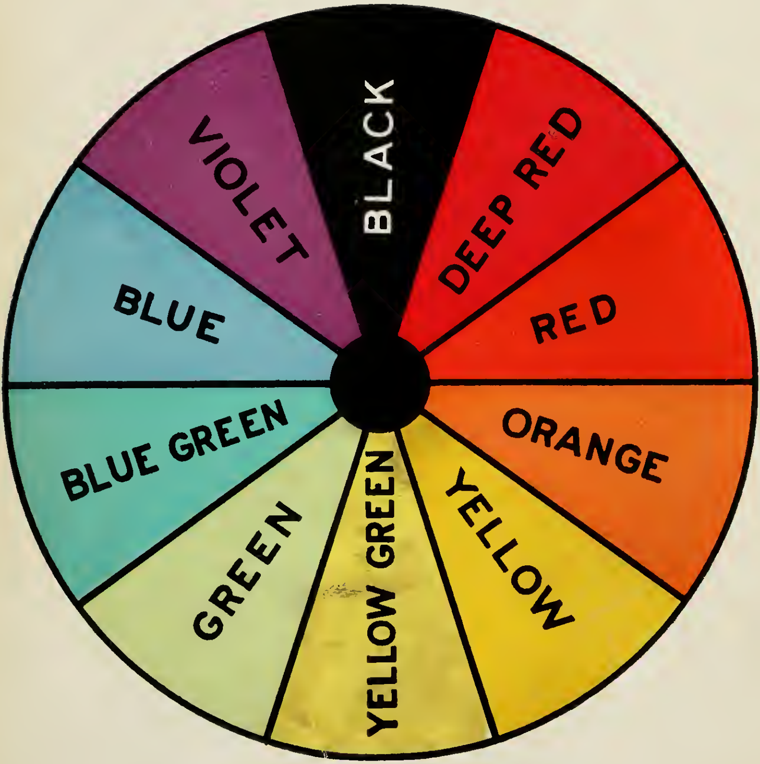
BLACK
DEEP RED
RED
ORANGE
YELLOW
YELLOW GREEN
GREEN
BLUE GREEN
BLUE
VIOLET

The Photography of Colored Objects

Third Edition

Eastman Kodak Co.
Rochester, N. Y.
1919

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PREFACE

THE first edition of "The Photography of Colored Objects" was written by Doctor C. E. K. Mees, who stated it was an attempt to put clearly the theory underlying the photography of colored objects and the application of that theory to those branches of practice which are of the most immediate importance.

While purely scientific terms and phraseology are not employed, no attempt has been made to be entirely "practical", since the application of an ounce of accurate knowledge may be worth a ton of unreasoning practice. No pretence is made of being unbiased, though it is hoped that there is no conscious bias. The Eastman products are freely discussed, but the loss of generalization caused by this procedure will be compensated by the advantage to be gained from definite information.

The large number of friends who have kindly assisted in the compilation of this volume makes it impossible to acknowledge all by name, and it would perhaps be invidious to mention only a few. We hope that all will understand that although they are not named we are none the less grateful to them for their various suggestions, and that we shall also be grateful for suggestions for the improvement of future editions.

EASTMAN KODAK CO.

ROCHESTER, N. Y.

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THE PHOTOGRAPHY OF COLORED OBJECTS

CHAPTER I

THE NATURE OF COLOR

AT the commencement of this book, which is essentially concerned with the analysis and photography of color, it will be well for us to get a definite idea as to what is meant by "color," and with what physical phenomena color is associated.

The nature of color is involved in the conception we obtain as to the nature of light. The nature of light has long been a source of speculation, and it was generally held that perception of light depended on the reception by the eye of small discrete particles shot off from the source of light; just as at one time it was held that the perception of sound depended upon the impact upon the ear drum of small particles shot off from the sources of the sound. This theory of light has the advantage that it immediately explains reflection; just as an indiarubber ball bounces from a smooth wall, while it will be shot in almost any direction by a heap of stones, so these small particles would rebound from a polished surface, while a rough surface would merely scatter them. This theory of the nature of light appeared adequate until it was found that it was possible, by dividing a beam of light and slightly lengthening the path of one of the halves, and then re-uniting them, to produce periods of darkness similar in nature to the nodes produced in an organ-pipe, where the interference of waves of sound is taking place. It could not be imagined that a reinforcement of one stream of particles by another stream of particles in the same direction could produce an absence of particles, while the analogy with sound suggested that, just

as sound was known to consist of waves in the air, so light also consisted of waves.

Light cannot consist of waves in the air, partly because we know that it travels through interstellar space, where we imagine that there is no air, but also because the velocity of light, nearly 200,000 miles per second, is so great that it is impossible that it could consist of a wave in any material substance with which we are acquainted. It is, however, supposed that there must exist, spread through all space and all matter, a substance which is termed the ether, and that light consists of waves in this ether.

Just as in sound we have wave notes of high frequency, that is, with many waves per second falling upon the ear, which form the high-pitched or shrill notes, and also notes of low frequency, where only a few waves per second fall upon the ear, forming the bass notes—so with light we may have different frequencies of vibration, some falling upon the eye at very short intervals, while other waves are of only half or even less frequency.

Since the velocity of light is the same for waves of different frequencies, it is clear that the waves of high frequency will be of shorter wave length than those of low frequency, the length of a light wave being the distance from the crest of one wave to the crest of the next.

The wave length of the light, like the velocity, varies with the medium in which the light is traveling. For instance, when light is traveling through glass, it will only have about two-thirds of the wave length of the light traveling in the air. But it is convenient to consider simply the wave length of light as the length of the wave in free ether, or for practical purposes, in air. White light consists of vibrations of many degrees of frequency, *i.e*, it consists of waves of various lengths; and a mixture of waves of all lengths in certain proportions forms what we term white light. If instead of allowing this heterogeneous mixture of waves to fall upon the eye, we omit waves of some frequencies from those entering the eye, then the brain will receive a sensation of color. Thus color is associated with wave length. White light being made up of waves of different lengths may be regarded as being made up of light of various colors, and by different devices may be split up into these colors.

We can analyse white light or discover the composition of any light with the spectroscope, an instrument by means of

which a small portion of the light to be examined is passed through a prism, transmitted by, or reflected from a diffraction grating. The result is that the light is split up into a band of different colors, which is known as the spectrum. If the light analysed is white these colors merge into one another without any break, but there will be a break or breaks (absorption bands) if the light examined is colored. Figure 1 shows the relative length of the waves corresponding with light of various colors, the diagram being drawn to scale. Since different length of waves correspond with different colors, a scale may be made in which the different wave-length numbers represented correspond in position with the different colors of the spectrum. The following diagram gives a simple arrangement of the normal spectrum, the numbers representing the length of the waves in Angstrom Units (A.U.), which are ten-millionths of millimetres, and the colors being placed against them:

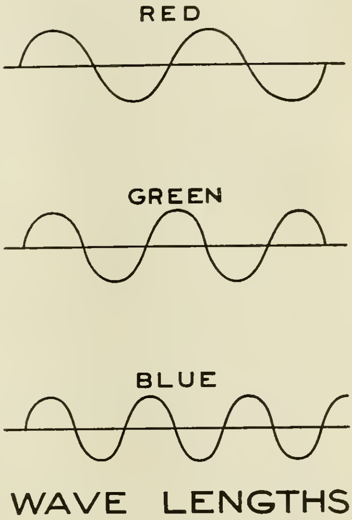


FIG. 1

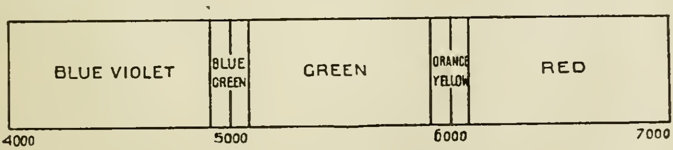


FIG. 2

It will be seen that the visible spectrum extends from 4,000 to 7,000. and is equally divided into regions which may be broadly termed:

Blue-violet	4,000	to	5,000
Green	5,000	"	6,000
Red	6,000	"	7,000

Light-filters, that is transparent media absorbing certain waves and transmitting others, can be constructed which will absorb some particular region of the spectrum, and they are generally called after the color they transmit; thus if we make a filter which only lets through the portion of the spectrum between 4,000 and 5,000, then we should call that filter a blue-violet filter, a filter letting through from 5,000 to 6,000 would be a green filter, and a filter letting through from 6,000 to 7,000 would be red in color. Thus from the spectrum we already derive the idea that light can be divided into three colors which we may call the primary colors, red, green, and blue-violet.

Remembering this conception of light, let us consider why we term a given filter red. It will appear red because it only lets through red light, but white light consisting of blue-violet, green, and red is falling upon it, so that clearly it is red because it stops or absorbs the blue-violet and green light.

Similarly, a piece of red paper is red because it reflects red light, but it has falling upon it white light consisting of blue-violet, green, and red, so that it must absorb the blue-violet and green light, not reflecting them, but only reflecting the red light. We are therefore justified in saying that anything which absorbs blue-violet light and green light together will be red.

It is this aspect of color, that objects are colored because they absorb, which must be clearly and definitely understood if the best results are to be obtained in the photography of colored objects. Unfortunately, however, the conception of color as an absorption is not common, though it is the most useful one, and it will be necessary somewhat to elaborate this idea in order to prevent misconceptions arising. We should form the habit of considering a red object, not as one that reflects red, but as one that absorbs blue-violet and green.

The importance of this definition is that it defines "red" without reference to the color of the incident light. Take a scarlet book and examine it by a light containing no red; such for instance as the mercury vapour lamp, in which red is almost entirely wanting. The book will no longer reflect red light because there is no red light for it to reflect, but it will still absorb the blue-violet and green light of the lamp, and will look black; it has not, of course, changed its nature, and we should still be justified in saying that it is red if we define red as we have done above.

In the same way a yellow object is not one which reflects yellow light (there is very little yellow light indeed in the spectrum, and if an object reflected only yellow light it would be so dark as to be almost black), but a yellow color is due to blue absorption. It reflects the other two components of white light, green and red, so that we should be justified in saying that yellow light consists of green light plus red light, but for our purpose let us consider yellow simply as a lack of blue; yellow is minus blue, so that if you have a beam of yellow light and add blue light to it, you will get white light.

Now what is green? Well, since white light consists of blue light, green light, and red light, green is clearly white light minus red and minus blue; and a green body is one which

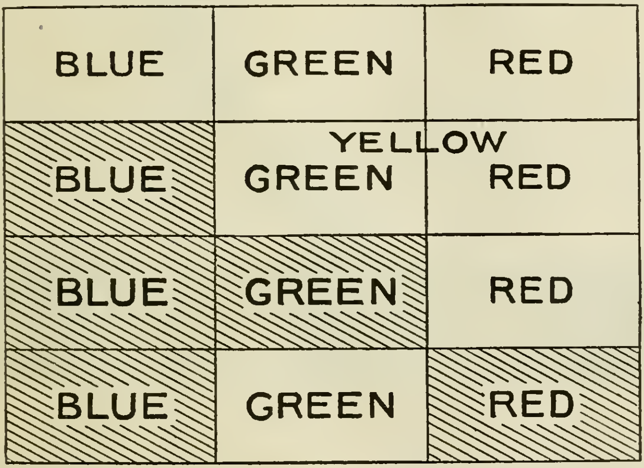


FIG. 3

absorbs both red and blue. The difference between a green object and a yellow object being that the yellow object absorbs blue only, whereas the green object also absorbs most of the red light which the yellow object reflects.

We can now make clear what is meant by complementary colors. As is shown in the diagram (fig. 3), white light consists of blue light, green light, and red light. The next section under this shows the blue blotted out, leaving the mixture of green and red—that is, yellow. We should say, then, that

yellow is complementary to the blue-violet. In the same way, in the next diagram all blue and green are blotted out, leaving only red, so that red is complementary to blue-green. In the bottom diagram all blue and red are blotted out, leaving only green; green is complementary to this blue-red mixture, which is usually known as magenta.

In general, then, the light absorbed by an object may be said to be complementary to that reflected by it.

So far we have only considered intense colors. We have

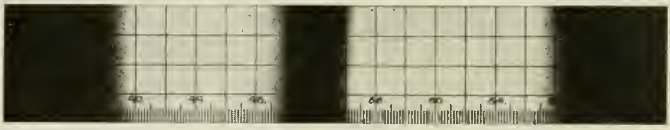


Fig. 4. Erythrosine Absorption Spectrum.

imagined that a red object absorbs the whole of the blue-violet and the green light, that is to say that its absorption was complete. But most things have only partial absorption—the absorption is incomplete. Partial absorption can be of two forms: it can be gradual, or it can be sharp; thus, if when taking a photograph of a spectrum there is put in front of the

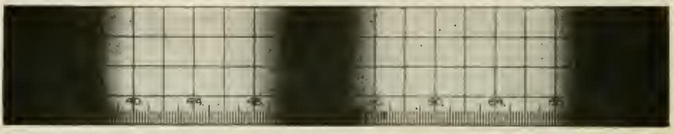


Fig. 5. Rosinduline Absorption Spectrum

spectroscope a solution of erythrosine then that erythrosine will absorb a clean patch of green from the spectrum between 5,000 and 5,400, as is shown in the photograph (fig. 4). But if you put in front of the spectroscope slit a cell containing rosinduline you will get a gradual diminution of intensity between about 4,900 and 5,600, with the least light transmitted about 5,200 (fig. 5). Thus different dyes and different substances give different classes of absorption, the two kinds being roughly subdivided into (1) sharp absorptions, and (2) gradual absorptions.

Let us examine the effect of a single sharp absorption band in different parts of the spectrum. First, consider a sharp

absorption band situated in the red about 6,500 and producing a total absence of red in this part. The remaining color consists of all the blue-violet and all the green, with some of the red. The actual visual effect of the mixed color is what one might term a "sky-blue." Imagine this band to

CHART SHOWING RESIDUALS

POSITION OF ABSORPTION BANDS

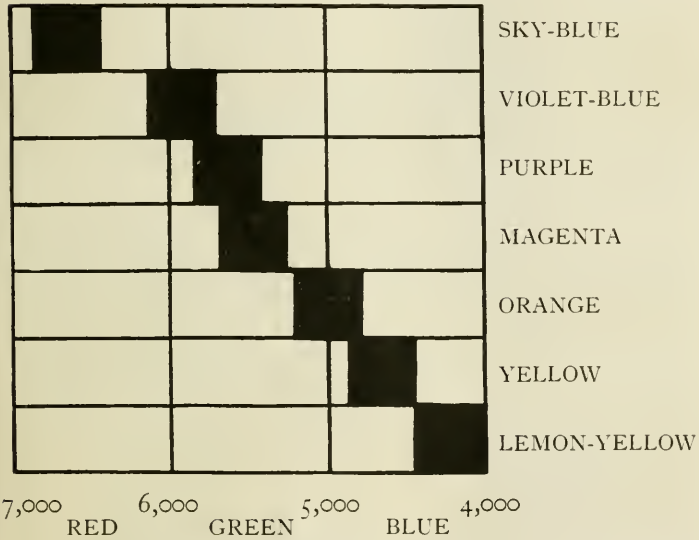


Fig. 6

shift so as to absorb the orange; absorbing between 5,800 and 6,200, the color will be a light violet-blue, because there is a great deal of red being transmitted and less green. If the band shifts into the yellowish green from 5,600 and 6,000 it will absorb a great deal of the green and none of the red, and the color will become bluish purple; as it shifts lower in the green towards the blue this purple becomes a reddish purple, so that when the band is situated at from 5,600 to 5,200 we have what is generally known as magenta in color. As the band shifts towards the blue, the blue fades out of the magenta, green taking its place. When the band is from 4,700 to 5,200 the color is a sort of orange, and as the band moves

into the blue-violet the orange becomes a yellow, and finally a lemon-yellow. So that if we imagine a single band to pass down the spectrum, we get a change from light sky-blue through purple, magenta, orange, and yellow, to lemon-yellow (fig. 6).

Now it will be seen that there is one class of color which does not enter at all into this series, namely, the greens. There is really no visual suggestion of green in any color formed by using a daylight spectrum and absorbing one narrow band only. In order to get a green we must have an absorption both in the red and in the blue. If we absorb the extreme blue and also the extreme red, we shall at once get a green, and as these two bands vary with regard to each other, we shall obtain various shades of greens. Thus, if the blue absorption band is weak, and the red absorption band is very strong, we get blue-greens; if the red absorption weak, and the blue strong, yellow-greens.

Green is almost the only common color due to two absorption bands, and other colors which on analysis prove to have two absorption bands generally tend to be mere variants in hue of some colors which we have already discussed under the heading of simple absorption bands. A brown color is fairly common, and the bands of a brown are of a gradual absorption type generally extending through the blue-green with a transmission band in the violet—that is to say, a brown is really a degraded orange, and is a variant on the color described as orange, resulting from a single absorption band in the blue green.

It is clear, therefore, that if a thing is colored sky-blue it means that it is absorbing the deep red, a violet-blue object absorbs the orange, a purple the yellow-green, a magenta the central green, an orange the blue, a yellow the blue-violet, and a lemon-yellow only the extreme violet. If a sky-blue object be looked at through a piece of yellow glass it will be found to look bright green in color, so that a green color is produced by the absorption both of the red and of the blue, the blue object absorbing the red light and the yellow glass the blue light.

Natural colors do not generally show sharp absorption bands, though the absorption bands produced by the stains used in microscopy are mostly fairly sharp. The same rule holds true, however; if a magenta object in nature does not signify a clean sharp absorption band in the green it still

means that that object absorbs far more of the green than of any other color, and, as regards photography, we can apply the rules deducted from theoretical residuals to natural colors. These rules are as follows:

1. If a color is to be rendered as black as possible then it must be photographed by light which is completely absorbed by the color; that is, by light of the wave-lengths comprised within its absorption band.

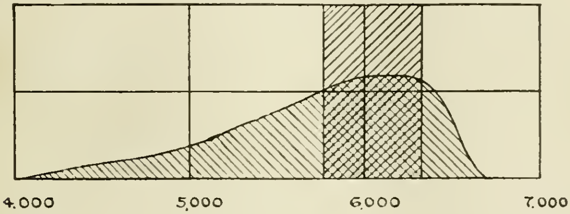


FIG. 7. THEORETICAL AND ACTUAL VIOLET

2. The second rule deals with the case where contrast is required, not against the background but within the object itself.

The proper procedure in this case is to photograph the object by the light which it transmits.

In fig. 7 we see a sharp absorption band depicted, which

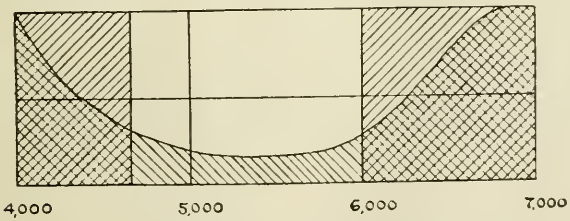


FIG. 8. THEORETICAL AND ACTUAL GREEN

would give rise to a violet-blue color. An actual violet-blue however, will have an absorption band of the type shown by the shading in the opposite direction on the diagram.

Similarly, fig. 8 shows an ideal green, having sharp red and violet absorption and an actual green with its gradual ending and absorption of the green itself.

The sharpness of absorption bands is of great importance in respect of the luminosity of the colors produced by them.

The side of an absorption band, which is toward the red end of the spectrum, generally has a sharp edge, as shown in fig. 7, while that which is toward the blue end has a gradual edge, a considerable amount of absorption remaining even in the transmitted portions of the spectrum. As a result, colors which are bounded by the sharp edges—that is, reds, oranges, and yellows—are bright colors, while colors which are bounded by the gradual edges—blue-greens, blues, and violets—are dark colors. A green will, as a general rule, have a sharp edge at its blue limit and a gradual edge at its red limit, and will consequently be of intermediate brightness.

If we divide the spectrum at 5,000 and at 6,000 so that we get three portions, 4,000 to 5,000 which we may term blue-violet, 5,000 to 6,000 which we may term green, and 6,000 to 7,000 which we may term red, then examination of the luminosity curve, given in Chapter II, fig. 10. will show that about $\frac{20}{30}$ of the whole light should be "green," about $\frac{9}{30}$ should be "red," and about $\frac{1}{60}$ should be "blue." But inasmuch as a bright red object will reflect nearly all the incident "red" light, while a bright green object will only reflect about $\frac{1}{3}$ of the "green" light, and a bright blue object $\frac{1}{4}$ of the "blue" light; a red object will be the brightest, a green object less bright, and a blue object very dark indeed.

A yellow, having only a single sharp absorption edge, is very bright. A yellow object usually reflects even more red light than a red object, and much more green light than a green object.

Dr. Mees made a number of measurements of the absorption by various filters and colors of the light which they are supposed to transmit or reflect, with the following results:

Pure Dye Filters

Transmitting	Region for which Transparency was measured.	Transparency, per cent.
5,900 to red end (tricolor red) .	Same filter	75
5,900 " " .	6,100 to red end	78
4,800 to 6,000 (tricolor green) .	Same filter	32
4,800 to 6,000 " .	4,900 to 5,800	35.5
4,000 to 5,100 (tricolor blue)	Same filter	11.5
4,000 to 5,100 " .	4,000 to 4,800	16.5
4,000 to 4,700 (D) (methyl violet)	4,000 to 4,600	15
5,600 to red end (E)	Same filter	69
5,600 " . . .	5,900 to red end	85

Transmitting	Region for which Transparency was measured	Transparency, per cent.
5,100 to red end (G)	Same filter	79
5,100 "	5,600 to red end	89
4,000 to 5,400 (H)	Same filter	14
4,000 to 5,400 "	4,600 to 5,100	16
4,600 to red end (K2)	Same filter	72.5
4,600 "	K3	85
K3	K3	81
K3	5,100 to red end	86
Light naphthol green (about 4,500 to 6,500)	4,900 to 5,700	40
Dark naphthol green	4,900 to 5,700	14.5
Xylen red (4,000 to 5,100), purest blue obtainable	4,000 to 4,700	41

The chief points of interest are the luminosity of the yellows (K2, K3, G); orange (E); and red (A); the darkening in the greens, and even more in the blues and violets.

Printing Inks

Bright scarlet	5,900 to red end	83.5
" "	6,100 "	88
Bright light blue	4,000 to 5,100	42

CHAPTER II

THE SENSITIVENESS TO COLORED LIGHT OF THE EYE AND OF PHOTOGRAPHIC PLATES

WE have seen that the eye distinguishes light of different wave lengths by the production of an appearance of color; thus a ray of light containing waves of a length of 4,600 of our units would be called violet, while if the waves were of the length of 6,500 the resultant impression on the eye would be said to be deep red. But the sensitiveness of the eye is not the same for waves of different lengths, and if we attempt to represent in monochrome the band of colored light called the spectrum (sunlight) as it appears to the eye, it will look something like fig. 9, the yellow-green light appearing bright-

FIG. 9. THE LUMINOSITY VALUE OF THE SPECTRUM AS IT APPEARS TO THE EYE

est and the yellow, orange, and red light on one side, green, blue-green, and blue on the other appearing progressively darker until the violet appears very dark and the visible spectrum ends.

The eye cannot perceive at all waves below 4,000 units, *i.e.*, what is known as ultra-violet light; neither can it perceive rays which are above 7,000 units, so that to these we must regard the eye as insensitive. The eye is very little sensitive to the extreme violet rays between 4,000 and 4,500. The blue affects it more and appears, as we say, bright. Between 5,000 and 6,000 the green appears as the brightest part of the spectrum; above 6,000 we have the bright reds, but the intensity rapidly falls off as the waves get longer, until beyond 7,000 we see practically nothing. We may also draw a curve showing the sensitiveness of the eye to the spectrum. It will be noted

that this curve has a maximum at about wave length 5,900, but this only holds for intense light. As the intensity of the light diminishes, not merely does the eye see less, but the relative sensitiveness of the colors changes somewhat, shifting towards the blue. This is what is known as "Purkinje's Phenomenon." The explanation offered for it by Professor Schaum is sufficiently interesting and little known to be worth repetition. It is known that the retina consists of rods and cones, of which the cones are considered to be color-sensitive, and the rods color-blind. In the part of the retina exactly opposite the center of the pupil there is a small depression which contains no rods, but only cones, and here it is

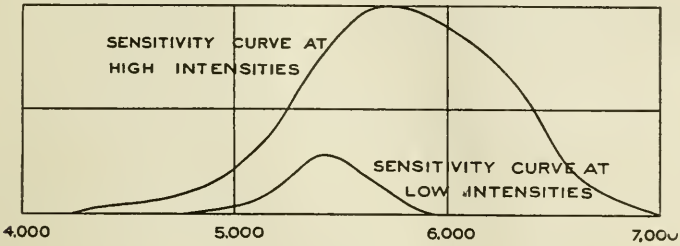


FIG. 10

found that the Purkinje phenomenon is non-existent, so that the intensity maximum remains constant. So that we may conclude that the color-sensitive cones alone display no Purkinje phenomenon, and that the phenomenon is due to the association of these cones with the color-blind rods. It is found that the sensitiveness curve for this region containing only cones is identical with the curve of sensitiveness for great intensities of light, so that this is the curve of the cones. On the other hand, since the rods are much more sensitive to feeble intensities of light than the cones, as is shown by the fact that the sense of light remains after color can no longer be distinguished, the sensitiveness curve of the rods will correspond with the curve for minimum intensity; so that for minimum intensity the sensitiveness curve is due to the rods alone, and as the intensity grows, the curve is more and more influenced by the cones, until with maximum intensity the curve of sensitiveness is almost entirely determined by the cones.

It is for the reason that in very weak lights the eye has a

maximum sensitiveness to a particular color, namely, a green, that the safelights supplied for use in the dark-room when Wratten panchromatic plates are handled are of this green color. The plate is sensitive to all colors, but an amount of green light can be used, if discretion is shown, that is sufficient to see by without too much danger of fogging the plate, whereas if a red were to be chosen, so much more would have to be used for it to make objects visible that the plate would inevitably be fogged.

Just as the eye is unequally sensitive to light of different colors, so a photographic plate is unequally sensitive to light of different colors. If we take an ordinary photographic plate and measure its sensitiveness, we shall find that it differs very markedly from that of the eye. The eye can see waves of no shorter length than 4,000 units; a photographic plate can see very much shorter waves, and can detect light which is quite invisible to the eye, this light being usually called ultra-violet, because it is beyond the violet. Also the maximum of sensitiveness of an ordinary plate is in the violet, and all the red, orange, and nearly all the green light is invisible to it. That is to say, the ordinary plate perceives objects only by the blue and violet light which they reflect, and this is a grave fault in the plate when regarded as an instrument for perceiving and recording colored objects, because the record which it makes of colored objects differs entirely from that which the eye makes.

It was found by Vogel in 1873 that, by treating plates with dyes, they could be given, besides their usual sensitiveness, a secondary sensitiveness in approximately the region of the spectrum which those dyes absorb. Thus if a plate is treated with a solution of erythrosine which absorbs the yellowish green, it will be sensitive to the yellow-green, besides being sensitive to the blue and violet. Plates which have been treated in this way are those which are known as "orthochromatic," the word implying that they can render objects in their true color values. The ordinary commercial orthochromatic plate, which is usually made by putting some eosine or erythrosine into the emulsion, has a sensitiveness curve of the type shown in fig. 11 (B), and it will be seen at once, on comparing this with the sensitiveness curve of the eye, that, although the plate is certainly better in consequence of this treatment with erythrosine, it cannot be described as at all comparable in sensitiveness with the eye. It has an

enormous excess of sensitiveness in the blue and violet, it has the sensitiveness to the ultra-violet which the eye has not at all, it then has very little sensitiveness indeed to the blue-green, a small maximum of sensitiveness in the yellow-green, and an absence of sensitiveness to the red. It may be assumed that if we take the blue to include the whole spectrum up to

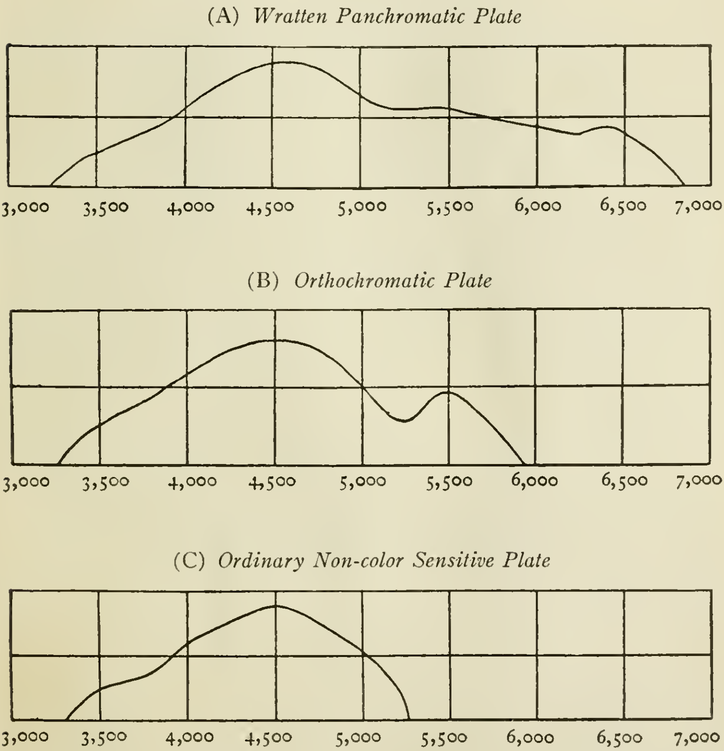


FIG. 11. DIFFERENT TYPES OF PLATE SENSITIVENESS CURVES TO DAYLIGHT

5,000, the green to be the spectrum from 5,000 to 6,000, and the red from 6,000 upwards, that the sensitiveness of the ordinary orthochromatic plate is distributed in the ratio of 40 parts in the blue, one part in the green, and none in the red. If we assume for the sake of argument that the eye sees the three parts of the spectrum as of equal intensity, then the

orthochromatic plate, besides the fact that it is not sensitive to the red, has only $\frac{1}{40}$ of the sensitiveness in the green that it would require to be equal in sensitiveness to the eye.

If, however, instead of sensitising a plate in the way we have described, we bathe the finished plate in a solution of certain of the dyes called isocyanines, we can prepare a plate which is very much more sensitive both to the green and to the red. Wratten and Wainwright were the first to succeed in preparing a plate commercially in this manner, the plate being sensitive to both green and red, and this plate they called the "Wratten Panchromatic Plate." The plate is sensitive to the whole visible spectrum; although it has a considerable excess of sensitiveness in the blue, this excess is very much less than in the case of the ordinary orthochromatic plates, and there are no absences of sensitiveness throughout the whole spectrum. The distribution of sensitiveness in this plate is also shown in fig. 11, and it may be said that $\frac{7}{8}$ of its sensitiveness is in the blue, $\frac{1}{16}$ in the green, and $\frac{1}{16}$ in the red; so that the sensitiveness to blue is seven times too great compared with the rest of the spectrum, while the sensitiveness to green and red together is $\frac{1}{8}$ of that required to have the same sensitiveness to the eye.

In order to attain the same relative sensitiveness as the eye, it is necessary with an ordinary orthochromatic plate or with the panchromatic plate, to use absorbing color filters which shall diminish the excess of blue light, and it is the consideration of these color filters and of the effect which they will have on the total sensitiveness of the plate, which must now be undertaken.

CHAPTER III

ORTHOCHROMATIC FILTERS

THE need for orthochromatic filters in photography is still insufficiently realized by many workers. For so many years photographers have been accustomed to the incorrect rendering of colored objects in monochrome which is given by ordinary photographic plates that a kind of photographic convention has been set up in their minds, so that a picture of a landscape in which grass is rendered as a dark patch, and a blue sky is almost white paper, is accepted without any feeling of its incorrectness; the more experienced a photographer, indeed, the more fixed this convention becomes, so that photographs taken under conditions which correctly reproduce the luminosities of the subject may sometimes appear over-corrected to a worker who has become accustomed to a "photographic rendering," and in whose mind the reproduction of a scarlet as dead black would raise no question whatever.

Recently, however, many photographers have become more critical in this respect, and it is beginning to be recognized that, so far as possible, photographs should correctly translate into monochrome the luminosity values of color as seen by the eye, and for this purpose correctly adjusted orthochromatic filters, films and plates are a necessity.

In order that we may understand the need for an orthochromatic filter let us take a simple example of a colored object such as that presented by a yellow daffodil. If we photograph side by side a daffodil and a narcissus on an ordinary photographic plate we shall find that although to the eye the yellow daffodil appears almost as bright as the white narcissus, yet in the print (fig. 12) the daffodil appears much darker, the difference being especially marked in the more deeply colored trumpet of the flower. Clearly the light which is reflected from the daffodil is deficient in some essential constituent which has much action on the photographic plate, although its loss does not make the flower seem much darker to the eye. If we examine the light reflected from the flower

by means of a spectroscope it will at first sight appear that we have the same spectrum as we got at first from white light, but on closer inspection we shall see that while the green, orange, and red regions are fully present, the blue light is dimmed and the violet light is almost completely absent. We

FIG. 12. DAFFODILS AND NARCISSUSES ON ORDINARY PLATE

thus see that the reason why the daffodil looks different from a white flower, appears "yellow" in fact, is that it fails to reflect all the constituents of white light, and absorbs the violet and blue constituents. These violet and blue constituents of white light are thus shown to be those which have a strong action upon a photographic plate, although to the eye they appear dark.

The frontispiece of this book shows a chart which is intended to represent the spectrum color both in hue and also

approximately in brightness and the strong action of the violet and blue rays, and the feeble action of the green, orange, and red rays is shown in fig. 13, which is a photograph of the frontispiece taken upon an ordinary fast plate. In this photograph the violet, blue, and blue-green patches, which are darkest to the eye, are reproduced light, while the rest of the chart appears dark.

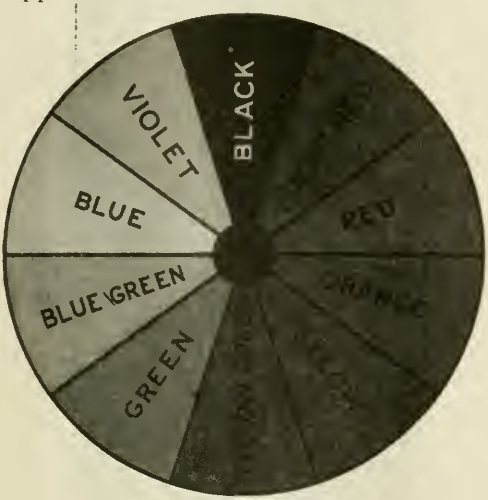


Fig. 13. Colored Chart on Ordinary Plate

If we take a photograph of the spectrum of white light upon this plate we get the result shown in fig. 14. It will be seen that the plate sees the colored rays in a very different

Fig. 14. The Luminosity Value of the Spectrum as it Appears to an Ordinary Plate

manner from the eye. The red, orange, and green colors which are bright to the eye appear quite dark to the plate,

while the deep violet light which is very dark to the eye is the brightest color to the plate, and in addition the plate will

FIG. 15. DAFFODILS AND NARCISSUSES ON PANCHROMATIC PLATE WITHOUT FILTER

demonstrate that there are rays beyond the violet which are quite invisible to the eye.

FIG. 16. THE SPECTRUM PHOTOGRAPHED ON A PANCHROMATIC PLATE

These ultra-violet rays are very strong in daylight and play an important part in the economy of the universe, being the chief cause of most of the effects which are produced by sunlight, such as the tanning of the skin, the fading of colored cloths, or the development of plants. They comprise, indeed, those constituents of white light which produce the "chem-

FIG. 17. TAKEN ON A WRATTEN PANCHROMATIC PLATE WITH K3 FILTER

ical" effects of light, and naturally they play a great part in the essentially chemical action of the exposure of a photographic plate.

The insensitiveness of a plate to the colors which are bright to the eye, and sensitiveness to those which are dark to the eye is of much importance in photography; in landscape photographs, for instance, the grass, which because it absorbs the violet and blue rays and also some of the red rays, appears

green, is always reproduced too dark, and white clouds are lost against the blue sky, although to the eye they appear much brighter, because the light from the blue sky is deficient in red rays, and these rays being bright to the eye their absence produces a strong effect. To the plate, however, which is blind to the red rays, their presence or absence is indifferent, and consequently the blue sky and white clouds appear of nearly the same intensity.

If we photograph the daffodil and the narcissus on a Wratten panchromatic plate we shall obtain a result which

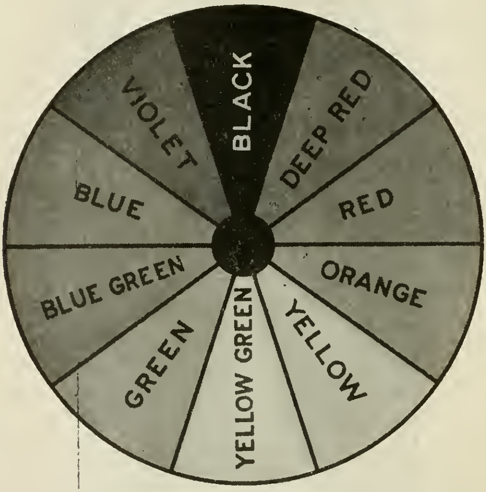


FIG. 18. COLOR CHART ON WRATTEN PANCHROMATIC PLATE WITH K3 FILTER

approximates much more closely to the truth than did that which we got with the ordinary plate, fig. 12. It will be noticed that in order to photograph the flowers they were placed in a vase; this was a white vase with a blue landscape painted upon it, and although the daffodils appear bright in the photograph, as they do to the eye, yet the blue design on the vase is almost invisible, although to the eye it stands out most distinctly.

A comparison of fig. 16 with fig. 9 will show the reason for this; the panchromatic plate is sensitive to green, orange, and red light, just as the eye is, but it is still very much too sen-

sitive to the blue and violet light, and to the invisible ultra-violet rays. Owing to the great intensity of these blue, violet, and ultra-violet rays in daylight, most of the photographic action, even on a panchromatic plate, is produced by them, so that the advantage gained by sensitizing the plate to the green and red rays largely is lost by their effect being drowned by the violet and ultra-violet rays. With artificial light (excepting mercury vapour and enclosed arc) the more actinic rays are weak, and a panchromatic plate gives at once manifestly better results than an ordinary plate.

In daylight we can secure a similar result if we modify the light reaching the plate by passing it through a filter or screen (usually attached to the lens), which removes all the ultra-violet light and as much of the blue and violet light as is necessary. *Such a filter or screen is called an "orthochromatic" or "isochromatic" filter.*

Fig. 17 shows a photograph of the daffodils and narcissuses in the vase taken through such a filter on a Wratten panchromatic plate, and it will be seen that not only are the flowers rendered correctly in their relative tone values, but also the design on the vase is clearly defined, as it appears to the eye.

In the same way fig. 18 shows a photograph of the frontispiece taken through a correctly adjusted (K3) filter on a panchromatic plate and represents the colors of the chart in their relative luminosities as they appear to the eye.

CHAPTER IV

THE EFFICIENCY OF ORTHOCHROMATIC FILTERS

WE have seen that orthochromatic filters are designed to remove the ultra-violet and so much of the violet light as is necessary to compensate for the extra sensitiveness of the plate to those rays.

Now in removing this light the orthochromatic filter increases the necessary exposure, because if we remove those rays to which the plate is most sensitive we must compensate for it by exposing the plate for a longer time to the action of the remaining rays, and the amount of this increased exposure will clearly be dependent both on the proportion of the violet and the blue rays which are removed by the orthochromatic filter, and also upon the sensitiveness of the plate for the remaining rays (green, orange, and red), which are not removed by the filter.

The number of times by which the exposure must be increased for a given filter with a given plate is called the *multiplying factor* of the filter, and this *depends upon the plate with which it is used.* It is meaningless to refer to filters as "two times" or "four times" filters.

Now, since it is always desirable that we should be able to give as short an exposure as possible, what is required in a filter is that it should produce the greatest possible effect with the least possible increase of exposure, so that a filter will be considered most efficient when it produces the maximum result with the minimum multiplying factor.

The ideal filter will, therefore, absorb *all* the ultra-violet light, and as much as is needful of the violet and blue light, but will transmit all the orange and red light which falls upon it. If a filter transmits any of the ultra-violet light, which it should absorb, or absorbs any of the green, orange, or red light, which it should transmit, then it will be more or less inefficient from that cause. An inefficient filter will, therefore, have a high multiplying factor compared with the correction which it will give, while, on the other hand, a low multiplying

factor for a filter may be due simply to insufficient correction. An efficient filter will have a low multiplying factor but will also give good correction.

Some of the earlier filters were made of yellowish brown glass, and a few such filters are still issued. Such filters are very inefficient, producing only a small degree of correction because they transmit a good deal of the ultra-violet and violet light, while at the same time they require a very considerable increase of exposure because they absorb much of the green light and even some of the orange and red rays, which should be completely transmitted. Much the same objection applies to the filters which are sometimes met with

FIG. 19. DIAGRAM PAINTED IN CHINESE WHITE ON WHITE CARD

made of green glass. These usually absorb the ultra-violet and violet light in a fairly satisfactory way, but the very strong absorption which they possess for red light causes an unnecessarily great increase in exposure if they are used with panchromatic plates, while, as they absorb a considerable amount of the green light they can not be considered efficient even if ordinary orthochromatic plates, insensitive to the red, be used.

For orthochromatic work all filters which are not a clear yellow should be disregarded; if the filter is laid down on a

sheet of white paper it should appear a bright or pale yellow, according to its depth, but it should not appear brown, and if it does appear brown, then it will be unsatisfactory in correction, and will require an unnecessarily long exposure. Compared with a modern "K" filter, a brown glass filter is as inefficient for photographic purposes as a spectacle lens compared with a modern anastigmat.

Nor is it sufficient for an orthochromatic filter to be yellow, for a yellow filter may still be inefficient, and the great criterion as to the efficiency of an orthochromatic filter which is clear yellow in color, and which therefore absorbs only a minimum amount of the rays which it should transmit, is that the filter should completely absorb the ultra-violet light.

We have seen that a photographic plate is extremely sensitive to ultra-violet light. Now some substances which are quite without color to the eye strongly absorb ultra-violet light; Chinese white, for instance, which is often used by artists for the highlights in drawings, and which appears quite white to the eye, absorbs ultra-violet light, so that when the drawings are photographed by an arc lamp upon wet collodion plates, which are chiefly sensitive to the ultra-violet, the Chinese white appears a dirty gray. Fig. 19 shows such a photograph of a diagram painted in Chinese white on a white card, the diagram being almost invisible to the eye but photographing as shown.

Moreover, ultra-violet light is far more easily scattered by traces of mist in the atmosphere than visible light is, so much so, that when Professor R. W. Wood took photographs by means of the ultra-violet light only, using a special apparatus, he found that if one could see the rays which he was using, even the clear atmosphere of the United States would appear to be continually filled with mist; so that the well-known photographic haze which so often spoils the distance in photographs taken on ordinary plates is due to the ultra-violet light, and our orthochromatic filter must be adjusted to cut out all of the ultra-violet light and just so much of the violet light as is necessary to produce exactly the effect of "atmosphere" which is seen by the eye. If too much violet light is removed by the filter all effect of atmosphere will be lost; but this effect, known as "over-correction," will be discussed later.

Now some yellow dyes, while removing violet light quite satisfactorily, transmit a great deal of ultra-violet light, and it is indeed possible to use one such dye to produce an anti-

orthochromatic filter; that is, a filter which will exaggerate instead of diminishing the false tone rendering to which photographic plates are prone.

Until a few years ago the dyes which were mostly used for the making of orthochromatic filters, while they gave clear yellow films and were stable to light, were unsatisfactory in that, except when very strong, they transmitted more or less ultra-violet light, and only the introduction of new dyes a few years ago made it possible for the first time to prepare orthochromatic filters of almost ideal efficiency, combined with great stability to light. Such filters are prepared by us under the registered name of "K" filters.

To illustrate the advance which the introduction of these filters marked there is shown in figs. 20 and 21 two photographs of the spectrum produced by the light of an electric arc burning between iron poles, the first taken through the K2

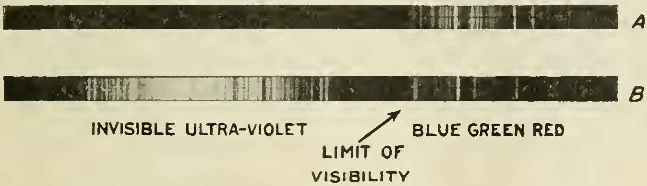


FIG. 20. (*A*) K FILTER   FIG. 21. (*B*) OLD FILTER

filter, the second through one of the best of the earlier filters, which is of almost the same depth to the eye and which requires about the same increase of exposure. It will be seen that while the green and red portions of the spectrum are as bright through the K2 filter as through the older one, the violet portion is much fainter and the ultra-violet is altogether absent, while the old filter is shown to transmit a very considerable amount of ultra-violet light.

Since the use of a filter is to compensate for the excess sensitiveness of even an orthochromatic or panchromatic plate to the violet and ultra-violet rays, it follows that plates of different degrees of sensitiveness will require filters of different kinds to produce the same effect as is seen by the eye. In the first place it is clear that no matter what filter be used, an orthochromatic plate which is not sensitive to red can never render tone values as they appear, from the very fact that the plate is red blind and that, except in a few unfortunate cases,

the eye is not. The most perfect filter, in fact, with such a plate can only give a result similar to that seen by a "color-blind" person. But even so it is not a matter of indifference what filter is used with a non-red-sensitive orthochromatic plate. If the filter be too strong the photograph will appear over-corrected. This over-correction will show itself chiefly in

FIG. 22. ABSORPTION OF SHARP CUT FILTER

the manner previously referred to, that is, the atmosphere in the distance will be lost; but also other unpleasant effects may be observed. In landscape, the sky may appear too dark (this is also the effect of under-exposure) and light grass may appear almost white; while in flower photography, yellow flowers may be indistinguishable from white ones. These defects are produced by a filter which too completely removes

FIG. 23. ABSORPTION OF CORRECT FILTER

the violet and blue light, as depicted in the diagram (fig. 22), instead of simply diminishing them to the required extent, as shown in diagram (fig. 23).

Provided, however, that a filter is satisfactory in this respect and does not produce over-correction, while at the same time it completely removes ultra-violet light, little is gained by adjusting a filter to a special orthochromatic plate, and the K1, K1½, and K2 filters, which have almost ideal efficiency and are free from any tendency to produce over-correction,

will give results as satisfactory as can possibly be obtained on plates which are not sensitive to red. The K3 filter, however, is of rather a different type, and brings us to the consideration of panchromatic plates. When panchromatic plates are used, since they are sensitive to light of all colors, it is possible to use a filter which will produce upon the plates a tone-rendering identical with that perceived by the normal eye, but in order to do this the filter must be carefully adjusted to the plate for which it is intended.

The older plates issued as panchromatic had very little sensitiveness to red and it was consequently necessary, in order to get correct rendering, to use with those plates filters which absorbed not only ultra-violet, violet, and blue light, but also green and even yellow-green light, thus allowing the undiminished red rays to produce their just share of action upon the

FIG. 24. PHOTOGRAPH OF THE SPECTRUM ON AN ORTHOCHROMATIC PLATE

plate. Similarly it is conceivable that a plate having an excess of sensitiveness to red and but little sensitiveness to green, might require a green filter to absorb the red rays as well as the violet and ultra-violet rays in order to allow the green to act more fully. All such filters as these require a very great increase of exposure, and for this reason they came but little into use. But fortunately the Wratten panchromatic plate is sensitive in the right proportion to green, orange, and red light, and all that is necessary to produce with this plate an exactly correct rendering of tone values is a clear yellow filter, removing the ultra-violet, and absorbing the violet and blue to a slightly greater extent than the K2 filter, thus requiring an exposure of not more than five times that needed for the unscreened plates. Such a filter is the K3 filter, which, however, is not to be recommended for use with other plates than the panchromatic plates, because, as a reference to fig. 24 will show, ordinary orthochromatic plates have a band of insensi-

tiveness to the blue and blue-green rays, and the K3 filter, by absorbing these rays to some extent, accentuates this defect.

While the K3 filter is required to produce full correction upon the Wratten panchromatic plate, so that the photographic rendering of tone values is the same as that perceived by the eye, yet very satisfactory results are obtainable by the use of lighter filters. From the point of view of correction it is of as great importance that the plate should be strongly sensitive to the green, orange, and red light as that the filter should be efficient and of sufficient depth, so that a Wratten panchromatic plate used without a filter at all, will, in some cases, give results superior to the much less color-sensitive orthochromatic plate used with a filter increasing the exposure four or five times. Moreover, the correcting action of such weak filters increases with the color-sensitiveness of the plate, while the more color sensitive the plate the lower the multiplying factor of the filter. Consequently, for satisfactory orthochromatic work the first essential is that the plate shall be as color-sensitive as possible, and then the choice of filter must be governed largely by the exposure which can be given, the K3 being used where full correction is desired, and where the duration of the exposure is of but little importance. For all-around work, however, the K2 filter will be found the most useful. When used with the Wratten panchromatic plate it gives a degree of correction slightly less than that obtained with the K3, but it requires only two-thirds of the exposure needed for the deeper screen.

Where short exposure is of greater importance than full correction the K1½ or the K1 filter should be employed; the latter requires only half the exposure needed for the K2 and notably improves the color rendering as compared with that given by the unscreened plate. This filter is also largely used for hand camera work, and the advantage obtained, even with such a weak filter, is very manifest in the results.

In some classes of landscape work it is desirable to produce over-correction; in surveying or tele-photographic work, for instance, where the utmost clearness and detail are desired rather than a pictorial rendering, it is necessary to remove all haze and atmosphere, and for this purpose, a strong yellow filter, such as the Wratten "G" filter, is best.

Owing to the depth of this filter, however, it can only satisfactorily be used with panchromatic plates, because with less sensitive plates its multiplying factor is very great, and the

exposure, which in any case is often considerable in tele-photography, becomes impracticable.

When selecting filters for telephoto work a K2 filter should be obtained as well as a "G", because in many cases the lighter filter is all that is required, and it has the advantage of requiring a shorter exposure.

For the photography of cloud forms against a blue sky a red filter may be used with great advantage, and the "A" filter is very suitable for this work. The results obtained show, of course, a greatly exaggerated contrast, but if the form of the clouds is all that is required such an exaggeration is not a disadvantage, though we should not recommend the use of so deep a filter in pictorial work.

CHAPTER V

THE MULTIPLYING FACTOR OF ANY SHARP-CUT FILTER

SUPPOSE that we have a filter which has a perfectly sharp absorption—that is to say, which cuts a clean section out of the spectrum, passing only light between two definite wave lengths, and without any absorption of that light—then, if we wish to find the multiplying factor of this filter, we must consider it in relation to the sensitiveness curve of the plate.

It will be convenient first to consider a filter which does not transmit light below 5,000 A.U., *i.e.*, which absorbs the whole of the ultra-violet and blue-violet, but does not absorb any

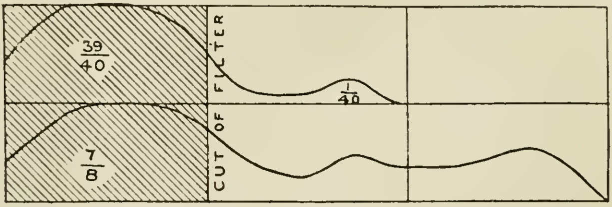


FIG. 25. SHARP-CUT FILTER ON ERYTHROSINE AND PANCHROMATIC PLATES

green or any red. This filter will be a bright yellow in color, yellow being, as we have seen, made up of green light and red light—that is to say, yellow being simply an absorption of blue. Consider the effect of this on an orthochromatic plate which has $\frac{39}{40}$ of its sensitiveness in the blue and $\frac{1}{40}$ in the green. The yellow screen will remove all the blue light, *i.e.*, $\frac{39}{40}$ of the active light, and it will increase the required exposure 40 times, so that it is what we term a 40 times screen.

Now consider the same screen to be used with the Wratten panchromatic plate. With this plate $\frac{7}{8}$ of the whole sensitiveness is in the blue, $\frac{1}{8}$ in the red and green. The screen will then remove $\frac{7}{8}$ of the active light, leaving only $\frac{1}{8}$ to act; it will increase the exposure 8 times. This example shows at once the

intimate relation between the plate and the multiplying factor of the filter.

Take now a filter cutting the spectrum sharply at 5,500. This screen will be bright orange in color. It transmits all the yellow-green, orange, and red light. It absorbs the blue-violet and blue-green light, *i.e.*, adopting our convention as to the division of the spectrum—it transmits the red and half the green, and absorbs the blue and half the green. The effect of this on the ordinary orthochromatic plate is to remove the blue sensitiveness, $\frac{39}{40}$ of the whole sensitiveness of the plate; but inasmuch as this plate is not sensitive to the blue-green, and the yellow-green region of sensitiveness which represents the other $\frac{1}{40}$ of the sensitiveness of the plate is transmitted by

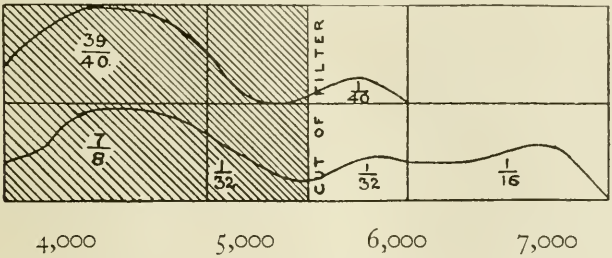


FIG. 26. SHARP-CUT ORANGE FILTER ON ERYTHROSINE AND PANCHROMATIC PLATES

the filter undiminished, the filter will only increase the exposure 40 times, being the same increase as is shown by the former screen.

On the panchromatic plate, however, the matter is different, $\frac{7}{8}$ of the sensitiveness of the plate is in the blue, and is removed by the filter, $\frac{1}{16}$ is in the green, and half of this is removed by the filter; so that the sensitiveness left is $\frac{1}{16}$, due to the undiminished red-sensitiveness, and $\frac{1}{32}$, being half of the green sensitiveness—the total residual sensitiveness, therefore, being $\frac{3}{32}$ of the original sensitiveness, and this filter will, on the Wratten panchromatic plate, increase the necessary exposure $10\frac{2}{3}$ times.

Again, consider a filter cutting the spectrum at 6,000—that is, transmitting all the red, but absorbing all the blue and all the green. The ordinary orthochromatic plate has no appreciable sensitiveness in the red, and therefore could not be used in practice with such a screen. The Wratten panchro-

matic has $\frac{1}{16}$ of its total sensitiveness in the red, and consequently this red filter will, on that plate, be a 16-times screen.

Let us now examine into the multiplying factor of the filter which will give correct reproduction of red, green, and blue, as seen by the eye. We have assumed in all these figures that, in order to get correct reproduction, the sensitiveness for red, green and blue should be equal; that is, we have chosen our units with that condition in mind. On the orthochromatic plate we have no red sensitiveness, but the nearest approximation to correct rendering that we are able to obtain will be given if the green and blue are of equal intensities, *i.e.*, we require a sensitiveness in the blue equal to the sensitiveness in the green. The sensitiveness of this plate in the green is $\frac{1}{40}$ of its total sensitiveness, so that we must use a screen which will give us $\frac{1}{20}$ of its total sensitiveness, $\frac{1}{40}$ being in the green, and

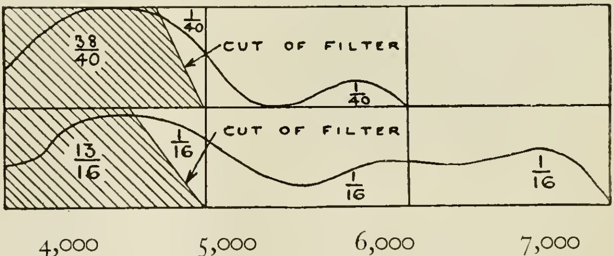


FIG. 27. ORTHOCHROMATIC FILTER ON ERYTHROSINE AND PANCHROMATIC PLATES

$\frac{1}{40}$ in the blue. That is, it must cut off 38 of the 39 parts of blue sensitiveness which the plate has, and the screen will increase the exposure 20 times.

With the Wratten panchromatic plate we have $\frac{1}{16}$ of the sensitiveness in the red, and $\frac{1}{16}$ in the green, consequently we must have $\frac{1}{16}$ in the blue; that is, the total sensitiveness will be $\frac{3}{16}$, and the increase of exposure required by the filter will be $5\frac{1}{3}$ times. This filter will reduce the $\frac{7}{8}$ sensitiveness of the blue to $\frac{1}{16}$, *i.e.*, it will remove $\frac{13}{16}$ of the blue sensitiveness. Two points must be noted here:

First that the panchromatic plate will require very much less exposure to correct it fully than will the orthochromatic plate, and secondly that, not only is less exposure required, but that a lighter screen is necessary; that is to say, in the one case we had to remove all but $\frac{1}{39}$ of the blue, but in the other $\frac{1}{13}$ of the blue was left, and consequently a screen which

would give the maximum correction obtainable on an ordinary orthochromatic plate will *over-correct* the panchromatic plate.

When working by artificial light (except enclosed arc lamps) the proportion of "color" sensitiveness rises, and that of "violet" sensitiveness falls, and these alterations greatly affect the multiplying factors of filters, as well as the relative sensitiveness of orthochromatic and panchromatic plates as compared with ordinary plates.

With tungsten lamps *almost full correction* upon the Wratten panchromatic plate is obtained by the use of the K1 filter.

A point of some interest, which is occasionally referred to in the photographic press, is the multiplying factor of two filters used, the one on the top of the other. It is often put as follows: Suppose we have two filters—a three times filter and a five times filter—how much will they increase exposure if used together? The increase can be found neither by adding nor multiplying the separate factors of each filter, but the answer must depend entirely on the nature of the filters, and somewhat on the plate. For instance, one might be a deep violet filter and the other a strong yellow, in which case it might be impossible for the two combined to let through any light! On the other hand, with a panchromatic plate, if one were a K3 filter and the other a filter in depth between the K1 and the K2, the effect would be negligible, and the multiplying factor (and correction) of the combined filter would be the same as that of the first one (K3) used alone.

If the plate is to be taken as the common orthochromatic plate and the filters are clear yellow filters, one being a K1 filter and the other a filter between K1 and K2, the combined multiplying factor would be about 7. If the filters were brown glass filters, of the type formerly used, the combined factor would probably be about 10.

While this paragraph may serve to inform some who have puzzled over the question, it is not to be taken as recommending the use of two filters together. Such a procedure is not at all desirable, especially on optical grounds.

Contrast Filters

These filters differ from orthochromatic filters in that it is not desired to obtain in them a gradually increasing absorption as shown in fig. 23, but as sharp a transition as possible between the region of absorption and that of transmission.

A red contrast filter (such as the "A" filter), for instance,

when examined in a spectroscope will be seen to give a spectrum like fig. 28 in which the absorption is complete up to the point where the yellow-green passes rapidly through yellow into orange, and at this point the absorption falls suddenly to almost nothing, practically all the orange and red light being transmitted.

To find the factors of these contrast filters we require to know only the relative sensitiveness of the plate to the part of the light transmitted compared with its sensitiveness to the part of the light absorbed. Assuming that a panchromatic plate has about $\frac{1}{16}$ of its total sensitiveness in the red and orange portions of the spectrum, about another $\frac{1}{16}$ being in the green, yellow-green, and blue-green portions, while the remaining $\frac{7}{8}$ is in the blue, violet, and ultra-violet regions, the factor of the "A" filter is consequently 16, since it transmits

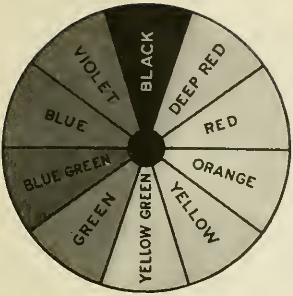
FIG. 28. SPECTRUM TRANSMITTED BY "A" FILTER

only the red and orange rays, to which the plate has $\frac{1}{16}$ of its sensitiveness.

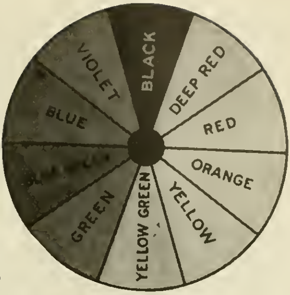
A useful strong yellow contrast filter is the "G" filter. This filter absorbs all the ultra-violet, violet, blue, and blue-green light, transmitting the remainder. On the Wratten panchromatic plate it has a multiplying factor of 8, with daylight.

Other contrast filters have approximately the following factors on the Wratten panchromatic plate:

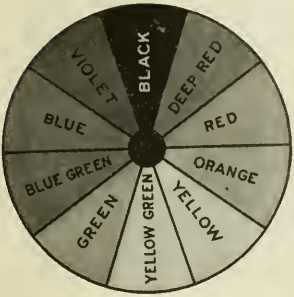
Filter	Color	Use	Multiplying Factor
A.	Red.	Tricolor work, Mahogany Furniture, Cloud photography .	16
B.	Green.	Tricolor work	16
C.	Blue.	Tricolor work	6
E.	Orange.	Two-color work, Contrast filter	12
F.	Strong Red.	Copying Blue Prints, Screen-plate Analysis	30



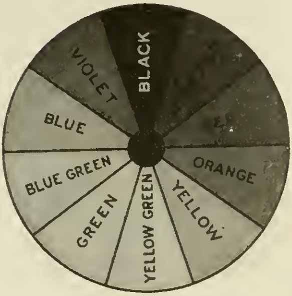
"F" Filter



"A" Filter



"G" Filter



"B" Filter

"P" Filter

"L" Filter

Fig. 29. Color Chart Reproduced Through Various Wratten Contrast Filters

Filter	Color	Use	Multiplying Factor
G.	Yellow	Telephotography, Furniture General Contrast . . .	8
L.	Violet.	Screenplate Analysis . . .	6
N.	Strong Green.	Screenplate Analysis . . .	24
P.	Blue-Green	Two-color work, Copying Typewriting . . .	15
R.	Deep Red.	Contrast.	80
Aesculine. containing	Colorless. Chinese White	Photography of drawings on Process Plate .	2
Infra-red filter, after Professor R. W. Wood		on the Spectrum Panchromatic plate	3,000

ORTHOCHROMATIC PLATE WITH WEAK FILTER

WRATTEN PANCHROMATIC PLATE WITHOUT FILTER

FIG. 30

The results obtained by photographing the frontispiece through these contrast filters are shown in fig. 29.

Beside these contrast filters special "M" filters are manufactured for use in photomicrographic work, and these are particularly recommended in conjunction with the Wratten "M" panchromatic plate for photomicrography. A description of these filters, instructions for their use, multiplying factors for them when used with the "M" plate for daylight and various artificial light sources, are given in our booklet entitled "Photomicrography."

With reference to the filter factors given above, it must be noted that these factors are only approximate, and constant endeavors are being made so to improve the color sensitiveness of the Wratten panchromatic plate, that the ratio of blue

sensitiveness to green and red sensitiveness will become lower and lower. At the time of this book's revision, the ratio is considerably lower, the red sensitiveness being so much improved that the factor with the red filter is not sixteen, but ten. The color sensitiveness is tested for every batch of plates, and the exact factors for eight filters are given on the instructions enclosed in every box of plates. These factors must be taken and not the merely approximate ones given in this book. The two illustrations herewith show the extreme red sensitiveness of the Wratten panchromatic plate. The one is taken on an orthochromatic plate containing its own filter, and the other is on the Wratten panchromatic without any filter whatever. The flower is a red anemone.

CHAPTER VI

THE RENDERING OF COLOR CONTRASTS

IT should be clear by now that by orthochromatic photography we intend to imply the use of a fully color-sensitive plate, such as the Wratten panchromatic, combined with a filter of necessary strength, to give approximately the same tone-rendering as that seen by the eye. It must be remembered in the first place that, to the eye, objects are picked out from their surroundings by contrast, and this contrast may be of two kinds, it may be tone contrast, that is the contrast of light and shade, or it may be color contrast. In the case of tone contrast, if we imagine ourselves to be dealing with a monochromatic scene, of a color within the limits of sensitiveness of the plate used, any plate will render tone contrast of considerable range as seen by the eye; but in the case of color contrast the question will require more careful thought. Suppose that we have two objects, the one contiguous to the other, and separated from each other to the eye purely by their color contrast, such as a green field containing a patch of red. The contrast between them is marked to the eye, although the tone contrast is very nearly nothing, that is to say, the two are of much the same visual luminosity. If we photograph them upon an ordinary plate both are black to it, and we get our contrast represented by one uniform field of black; the color contrast has disappeared, and we have a totally unsatisfactory rendering of that which we are photographing. If, however, we photograph them upon a green sensitive plate, then the green will be distinguished from the red as brighter, and we shall get a certain degree of contrast of a kind, but if we photograph them upon a panchromatic plate with a K3 screen, so that we get a rendering of both colors in their true luminosity value to the eye, the contrast again disappears, and the colors are represented by a uniform field of gray.

What then must we do to obtain a satisfactory rendering of this color contrast? Clearly it is not possible to render the color contrast accurately in monochrome, so long as we retain the rendering of correct luminosity values for our colors, and

consequently we must sacrifice the correct rendering of either the red or the green. If we use a paler filter or a green filter, the green will appear the brighter and the red the darker; if we use a deep orange filter, the red will be brighter, the green darker; and which we shall use must be governed by circumstances. As a general rule, if we must correct wrongly for the rendering of color contrast, it is usually better to over-correct towards the red, since red is a strong color, while green is a weak. For example, in a field of grain of a deep yellow color, we may have poppies standing out which are nearly as bright as the grain, and it is necessary to decide whether we shall render them as brighter or as darker than the grain. Probably on an actual measurement of luminosities they would be a little darker than the grain, but remembering the way in which the strong red attracts the eye, it would seem that a more faithful rendering would be given by over-correcting and rendering the poppies as brighter than the grain. Again, the top of a yellow straw stack against a deep blue sky may give a result with perfect orthochromatism where the haystack is indistinguishable from the background. Here again it is probably better to over-correct, though the individual worker must decide for himself. A thing to guard against always is the danger of basing one's consideration of monotone rendering upon photographs; we are apt to take our conception as to the tone value of bright green grass, for instance, from photographs which invariably have shown it as too dark, if not black. Frequently, in a spring landscape, the hedges and grass are almost the brightest things in the whole landscape, and they should clearly be rendered as light grays; but so uniform is the belief among photographers that grass is black, that a rendering as light gray will often provoke the comment that the photograph is over-corrected.

The most important case of color contrast occurs in the copying of pictures, and for this purpose Dr. Mees some time ago suggested a special method, which may be explained here. This method depends upon the use of tricolor filters, the plate being exposed first through one filter and then through another, in order to get the desired color-rendering. It is first necessary to remove a common misconception, which one frequently finds repeated in text-books and the technical press, namely, that the effect of printing from the three tricolor negatives on one piece of paper would be to give an orthochromatic result. This would give an isochromatic result, that is to

say, one in which all colors are rendered of equal strength, independently of their visual brightness; this results in an excess of brightness in the red and blue, especially in the blue, and insufficient brightness in the green, the whole color-rendering being wrong. Suppose that we put a set of filters in front of our lens, fitted in a slide-past holder, so that we can expose the plate through the three filters in succession without removing the plate or dark side. Then we may give an exposure through the three filters, in proportion to their ratio upon that plate. Supposing, for example, that we have a plate and a set of filters, such that the blue requires 6 times the normal exposure, the green requires 12 times, and the red requires 18 times, if we give through the blue twice the normal exposure, the plate will be ⅓ exposed. Now give through the green 4 times the normal exposure—the plate is now ⅔ exposed—and now superpose on this an exposure through the red screen of 6 times the normal exposure; we have now a negative combining our three color negatives in one; but it will not be correct rendering at all, it will give all blues much too light, and greens too dark, and the results will be unsatisfactory. With the Wratten filters and plate, owing to the fact that the green transmits a certain amount of blue, correct color-rendering is obtained by giving ⅔ of the exposure through the green and ⅓ through the red. Thus, in the example just given, where the ratio of exposures for the three filters was 6—12—18, the correct rendering would be obtained, together with correct exposure, by giving about 8 times the normal exposure through the green and 6 times through the red. Since the proportion of the mixed exposures of green and red gives a correct orthochromatic result, we can exaggerate red or green by increasing the exposure of the one filter and diminishing the exposure of the other. For instance, if we give 9 secs. exposure through the red, and 6 secs. through the green, we shall have exaggerated red at the expense of green; on the other hand, if we give 10 secs. through the green and 3 secs. through the red, we shall exaggerate greens at the expense of reds. If we want to diminish greens altogether, and bring up reds and blues, we can use our red filter and blue filter, and so obtain the rendering that we desire by altering the relative exposures through the three tricolor filters.

This method may sound rather far-fetched, but as a matter of fact it has been adopted by some very skilled picture

copiers with perfect success. A very important point about this method is that all the while one is working one knows how far one is from correct rendering, so that instead of more or less over or under-correcting by a screen of which the action is somewhat uncertain, one can say quite definitely: "I exaggerated the reds in that reproduction 50 per cent., because it was necessary to pick out the red against the green in the shadows"— a statement which is more scientific and more useful, both to the speaker and hearer, than a statement such as: "I used a rather dark screen for that in order to get over-correction."

A word of warning is necessary here as to the quality of the filters required for this. It will be seen that the three images are literally superposed upon one another, and that the very smallest shift in any one of these images will produce a double image in the result, consequently a much higher grade of filter is required than for ordinary reproduction purposes. It is not sufficient that the images should be of the same size, but they must actually fall on the same place on the focusing glass. This can only be accomplished by the use of filters cemented in optical flats of the very highest quality, or else by the use of gelatine film alone. It will save disappointment if the fact is emphasized that what are usually known as "first-class cemented filters" will not do for this, and even when using flats care should be taken always to insert the filters the same way.

Color Contrast for Special Purposes

The type of color contrast which we have been describing is simply a concession from orthochromatism, in order to enable us to some extent to make up for the failure of monotone when it is necessary to render color. But there is another case of the photography of color contrasts, which is to the technical worker of as great if not greater importance, and that is the photography of colored objects, as such in order to obtain the best possible results, generally for reproduction purposes.

General Principles.—If a color is to be rendered as black it must be photographed in its absorption band (see Chapter I) by light which is of such a wave length that it is completely absorbed by the color. That color then appears as black as it can be made. A useful example is given by a photomicrograph of a section stained with eosine: this section is pink; if it is viewed by blue light, owing to the fact that eosine does not

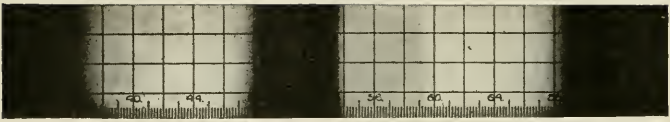
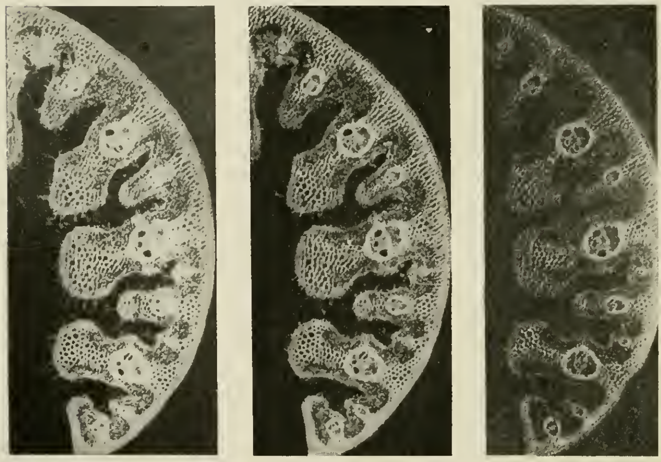


Fig. 31 Absorption of Eosine



5,000-5,400 5,700 6,400

Fig. 32. Negatives Made by Means of Light of Above Wave Lengths

absorb blue, it looks comparatively light. By green-blue light of a wave length about 5,000 to 5,400, which is completely absorbed by eosine (the absorption-spectrum of eosine is shown in fig. 31), the section is entirely black, as is shown by the first block; being blocked up in detail, this gives the maximum degree of contrast (fig. 32). Photographing at 5,700, on the border of the absorption band, we get a considerably lessened contrast, which for this particular section will give us the best result. There is plenty of detail in the section, while at the same time the contrast is sufficient for reproduction purposes. Photographing at 6,400 in the red, and in the light which is completely transmitted by the section, the photograph has no contrast, is very flat, and results are useless. So that for the maximum contrast we must photograph in the absorption band.

For example, it is sometimes necessary to copy a print of which the paper has become yellow with age. An ordinary plate is sensitive only to the ultra-violet, violet, and blue rays, which are more or less absorbed by the yellow paper, so that if a negative is made of such a print on an ordinary plate the reproduction of the yellow paper will appear dark, or, in any case, dirty. If a color-sensitive plate is used with a yellow contrast filter the yellow stain will have no effect and will fail to photograph. It should be noted that the yellow filter for such a purpose should not be an orthochromatic filter if the best results are required, but a much stronger filter, such as the Wratten "G" filter, because an orthochromatic filter is adjusted to photograph objects in their relative luminosities as seen by the eye, and if the yellow stain is visible to the eye it will also photograph through an orthochromatic filter. If the stain be examined through the strong "G" filter there will reach the eye no light which is not yellow, and so the stain will not appear different from the white ground.

Fig. 33 shows two photographs of a Velox print which had been splashed with yellow dye so as to leave a yellow stain. In the upper photograph, taken on an ordinary plate, the stain appears quite black, while in the lower one, for which a panchromatic plate has been used with a "G" filter, the stain has entirely disappeared, only a trace, which cannot be reproduced, being visible in the negative.

Another difficulty is sometimes met with in copying prints due to the fact that the prints are of a brown color, such as is given by sepia toned prints. This brown color has a very

On Ordinary Plate

On Panchromatic Plate with "G" Filter

FIG. 33. YELLOW-STAINED VELOX PRINT

much stronger absorption for the violet light, to which the plate is sensitive, than for the yellow-green and orange light, which represents the maximum sensitiveness of the eye, and consequently such prints when photographed on a non-color sensitive plate give negatives having far too much contrast, and with blocked up shadows, and it will generally be found that no increase of exposure will reproduce satisfactorily such photographs. The obvious course is to photograph them as the eye sees them, that is by means of a fully correcting filter and a panchromatic plate.

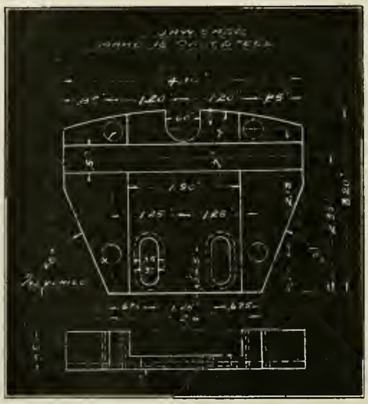
A difficult task without the proper plate and filter is the photography of engineers' and architects' blue prints. Ordinary orthochromatic plates with yellow filters do not give the best results with such a subject because a great deal of the yellow-green light to which such plates are sensitive is reflected by the blue, and in order to obtain really first-rate results the "A" or "F" filter should be used with "Process Panchromatic" plates, thus photographing the print by red light which is completely absorbed by the blue color. With such a plate and filter the results from a blue print are in every way as satisfactory as could be obtained from a black and white print in the ordinary way (fig. 34).

Suppose, to take another example, we have a sheet of typewriting, with corrections in red ink; the purple typewriting absorbs the whole of the orange and green, the red ink absorbs only the green. If we photograph through the green filter, "B", of the tricolor set, we shall get both the typewriting and the red ink completely black, and therefore the greatest contrast which can be obtained (fig. 35). If, on the other hand, we photograph through the red "A" filter, the typewriting will appear plainly visible, but the red ink will show so little contrast that it easily can be intensified out of existence, and we can make a reproduction of the sheet showing the typewriting only (fig. 36).

Most commercial work, such as catalogue illustrations of carpets, wall papers, linoleums, china, marble, etc., can best be accomplished by the aid of the K3 filter on the panchromatic plate, but occasionally a red or green filter will be found extremely useful. For general commercial photography the following set of filters will be found to cover most requirements: K1, K2, K3, tricolor set (red, green, and blue), strong red ("F"), and strong yellow ("G").

For one branch of commercial photography, furniture work,

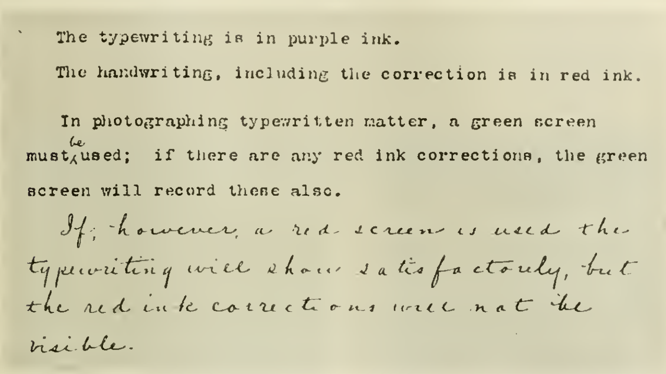
(*a*) Blue print photographed on Ordinary Plate



(*b*) Blue print photographed on Panchromatic Plate through "A" Filter

FIG. 34

the tricolor red "A" and the yellow "G" filters are invaluable; the "A" filter used with the panchromatic plate giving a splendid rendering of the grain of red mahogany such as can


The typewriting is in purple ink.

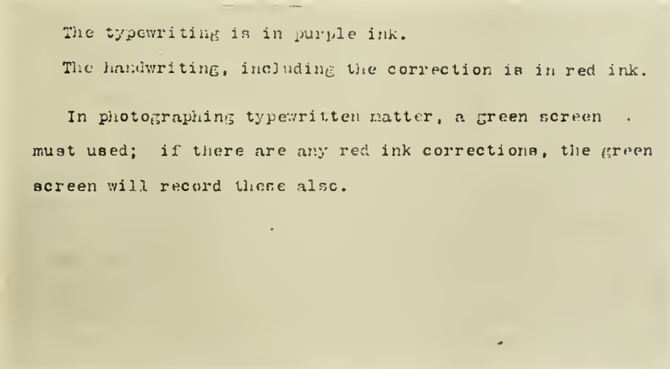
The handwriting, including the correction is in red ink.

In photographing typewritten matter, a green screen must be used; if there are any red ink corrections, the green screen will record these also.

If, however, a red screen is used the typewriting will show satisfactorily, but the red ink corrections will not be visible.

Fig. 35. Typewriting and Red Ink Through Green "B" Filter

be obtained in no other way. For satinwood and inlaid work the "G" filter is required, so that for furniture photography


The typewriting is in purple ink.

The handwriting, including the correction is in red ink.

In photographing typewritten matter, a green screen must used; if there are any red ink corrections, the green screen will record these also.

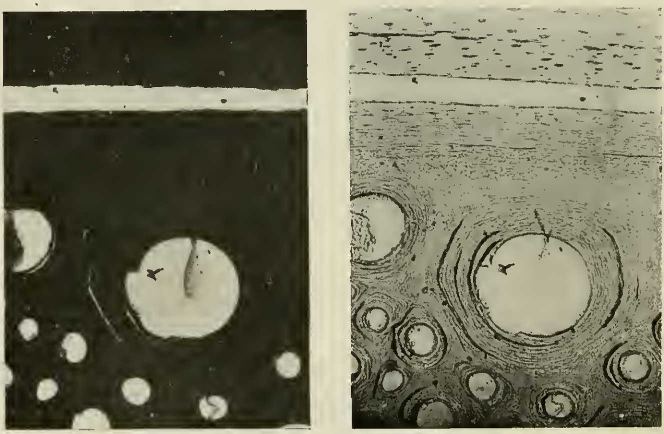
Fig. 36. Typewriting and Red Ink Through Red "A" Filter

a set comprising the K3, "G", and "A" filters should be obtained.

Subjects for which a correctly orthochromatic rendering is

particularly desirable are postage stamps and reproductions of colored advertisements, such as posters.

In copying maps a K3 filter must be used if the map contains several colors, but in the maps which more often come to the commercial photographer, such as land survey maps, a contrast filter is frequently required to accentuate some special color in the original.



Whalebone Section Photographed for Contrast

Whalebone Section Photographed for Detail

FIG. 37

For photographing new houses, and indeed most modern architecture, the K3 or "G" filter with a panchromatic plate will give admirable results, especially in dull or hazy weather.

By the application of this principle, viz.: to use a filter that absorbs the color which is to be rendered as black, we can pick out, in fact, any color from a combination of colors, and in two, three, or four printings obtain a facsimile result.

The second principle of importance is that, where a uniformly colored thing is to be photographed, and the best rendering is to be obtained, it must be photographed not in its absorption band, but in the transmission or reflection region of the color. For instance, in photographing the eosine-stained section, we get the greatest contrast by photographing in the absorption region of the stain; but we obtain that contrast at the expense of the loss of detail in the section, and we

get the greatest detail in the photograph where we used the red light. Owing, however, to the fact that we must keep contrast against the *background* in this case, our best final result was a compromise between contrast and detail, obtained by photographing on the border of the absorption band. A very good example, however, of the use of light, such as is transmitted by the stain, is shown by the two photographs of a whalebone section, which are reproduced here from the little book on "Photomicrography." The upper one shows the section photographed for contrast by means of light which is absorbed by it; the lower one shows the same section photographed in order to show detail by the light which it transmits (fig. 37).

Perhaps the most important application of this method occurs in the photography of furniture, where the results are simply surprising to the uninitiated. If a piece of reddish mahogany is photographed on an ordinary plate, no trace of grain is usually visible. The photograph is made by blue light to which both the red darker portions and the yellow light portions are black; to give an increased exposure simply results in the photography of a plentiful crop of normally invisible scratches. If, however, a panchromatic plate sensitive to the red is used, with an orange or, better, a red filter, the results are entirely different; the scratches disappear and the grain comes up in the most wonderful way; in fact, so startling is the difference, that probably many readers will think that the example shown in Fig. 38 is faked, but if they try the experiment they will get similar results. Some examples and hints on this work are given in the booklet, "Color Plates and Filters."

It must be noted that for this purpose the plate must be red sensitive, as red mahogany has a strong absorption in the greenish yellow of the ordinary isochromatic plate, and it may be well to remark again at this point, as at the beginning, that the whole of the discussion of this book is based on the use of plates that are panchromatic. Ordinary and regular orthochromatic plates may be ruled out when we are dealing with technical work, which requires us to work in any region of the spectrum which may be necessitated by the color of our object.

A useful example of this same principle of photographing in the colored light which is reflected from the object, is given by the photography of prints for reproduction purposes. We

On Ordinary Plate

On Wratten Panchromatic Plate through Orange Red "A" Filter

Fig. 38

have already referred to the case of brown prints, and in the same way a red silver print, when being photographed on wet plates for half-tone work, is well known as a most difficult subject, requiring usually a large amount of fine etching. These, and other cases of the same kind, can be dealt with very easily by using Wratten panchromatic plates with a medium filter. The prints then become as easy to copy as any black-and-white subjects.

CHAPTER VII

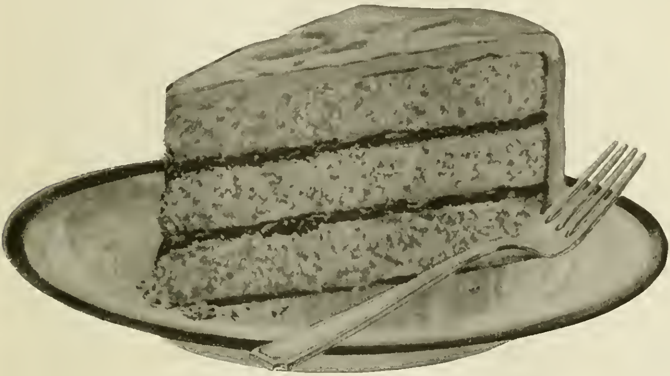
PORTRAITURE

IN no branch of photography is the reproduction of colored objects in correct monochrome of greater importance than in portraiture, and in no branch is it in greater danger of being ignored. The flesh tints, with which portrait photographers are mainly concerned, are chiefly of a reddish or yellowish nature, while the yellow and brown shades of the hair and the variety of the eye-colors, apart altogether from the clothing, cause every sitter to present a distinct problem in color reproduction. Earnest efforts to meet this problem have been to a large extent discouraged by the assistance which the retoucher can give in correcting the errors introduced by incorrect color-rendering. Retouching, however, is always a dubious remedy, and though expert artists may make good use of it, it leads to many pitfalls for most workers. We have only to look at a lantern slide, made from a retouched portrait and projected upon the screen, to realize how difficult it is for retouching to be applied satisfactorily. When making an ordinary enlargement it is often necessary to remove the whole of the retouching, so badly does it show. Even if the retoucher were able to lighten satisfactorily those parts of the flesh which the ordinary plate has failed to render with sufficient density, he would still be unable to darken correctly these parts where the excess of sensitiveness to blue and violet has produced too heavy a deposit in the negative.

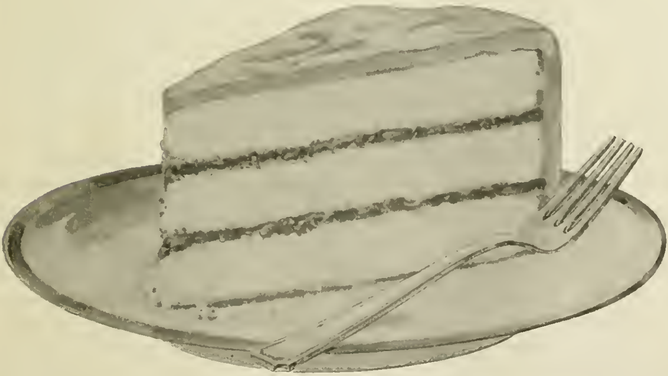
The rendering of color in portraiture is governed by the same laws that govern the reproduction of color in other subjects. Those who have studied the earlier chapters of this book will realize that photographing with ordinary plates is equivalent to photographing by blue-violet light, to which alone such plates are sensitive. As blue-violet light is absorbed by flesh tints, the use of it produces an accentuation of contrast similar to that which always follows when any colored object is viewed or photographed by light which is selectively absorbed by it. (See Chapter V.)

Consequently portrait negatives taken upon ordinary plates always show more contrast than the subjects appear to the

eye. To overcome this difficulty the subject may be either lighted with a softer, flatter light than would otherwise be used, or the negative may be over-exposed. But in either case accuracy of tone-rendering in all the portions of the pic-



(*a*) On Ordinary Plate



(*b*) On Panchromatic Plate with K3 Screen

FIG. 39

ture which are *not* yellow or red is lost, and, to put it as it appears with analysis, the "lights" are degraded.

Not only is this general accentuation of contrast produced, but also the reproduction of the skin itself, which is really the fundamental work of the artist, suffers greatly from the

contrast effect introduced by the use of plates insensitive to red. Fig. 39 will possibly make this clear. The photograph of the cake is taken from a lithographic advertisement in which the cake appears to be very faintly mottled in many colors, mostly orange and red. These spots being not only small, but alike in hue, are nearly invisible to the eye; so that in the original it appears smooth. When it is examined by violet light, however, the violet light is completely absorbed by the yellow, brown, and red spots, and consequently, as was explained in our discussion of color contrast, the contrast between these and the background is increased greatly. So that when the original is photographed on an ordinary plate a high degree of contrast is produced, and the photograph looks very mottled. Photographed upon a panchromatic plate with a K3 filter, we obtain an accurate reproduction of the lithograph, giving the same degree of smoothness as was apparent to the eye. This shows at once how any uneven stipple, such as this grain exhibits, produces this mottled, and to some extent woolly, appearance by color contrast.

This exact effect is reproduced in photographing the skin. The surface of the skin is completely heterogeneous. The small blood-vessels which cover it, and the pathological changes, which the failure of the pores of the skin to do their work perfectly produce with increase of age, make a sort of stipple of reddish spots and streaks over the whole surface of the skin.

This is very easily seen by examining any portion of the skin under the mercury vapor lamp. The light from the mercury vapor lamp consists for essential purposes of a mixture of green light and violet light, no red being present. The small red spots of the skin absorb very completely the green light from the mercury vapor lamp, but reflect to a considerable degree the violet ray, thus producing a general background of white light stippled over with violet spots. The same effect can be seen to a less extent by examining the skin through a green filter, when the mottling becomes much more marked than it is to the eye, but appears of course black, and not violet.

The same unfortunate contrast which produces this effect on the skin also accentuates wrinkles. Wrinkles are generally lined by small networks of capillaries, which have the practical effect of producing a red line on each side of the wrinkle. This, photographing black on the ordinary plate, greatly

accentuates the depth of the wrinkle. The wrinkle at the side of the eyes is often deep red in color, and consequently prints too dark when photographed by any but red sensitive plates, while the delicate shadows under the lower eyelid which give roundness and shape to the eye are seldom truthfully rendered with the ordinary plate, though when they do appear the retoucher generally removes them.

Sunburned freckles are of course yellow and, again completely absorbing the violet, appear as black spots. The two portraits of the lady (Fig. 40) were taken, the one on a panchromatic plate with a K3 filter, and the other on an ordinary plate, exposures being given which render the neutral detail the same in the two cases. The accentuation of freckles and wrinkles with the ordinary plate is of course very marked, but on observing the skin texture, the point as to general smoothness will also be realized, though this is somewhat lost in the reduced reproduction.

An instance of the opposite fault to that of insufficiently recording red or yellow markings upon the plate, and thus accentuating their appearance, is shown by the way in which any bluish tinge produces too great a density and prints too light. The best example of this is possibly the mouth. The upper lip being usually rather more in shadow and reflecting less ultra-violet, appears black in a photograph taken upon an ordinary plate, but the blue, violet, and ultra-violet has its full effect from the lower lip, and that, therefore, reproduces unnaturally white, so that the mouth is more often like a quarter of an orange than a rosebud.

When dealing with the question of color contrast, it was shown that while photographing in the absorption band of a color produces contrast, photographing in the transmission band will produce an entire lack of contrast. Clearly then, the deeper the filter we use, the smoother the result will become, and, indeed, if a portrait be taken through the red filter used in tricolor photography, the failure of contrast is so complete that the skin appears absolutely smooth, giving quite a false impression. There is, however, an application of this general principle of photography in the transmission band which we must next consider, and that is in the question of the hair.

This subject is of great importance to photographers, because of the extreme difficulty in satisfactorily retouching hair.

Brown, golden, or red hair is always difficult to photograph,

On Ordinary Plate

On Panchromatic Plate with K3 Filter

FIG. 40

tending in the darker shades to produce black masses without detail. Golden hair is usually met by using a dark background (with a little paint on the back of the negative, as a correspondent ingenuously remarks), but this imposes a needless limitation, and will not meet the not infrequent case of a light golden brown moustache. Moreover, hair of these colors, even when exposure and lighting have produced a satisfactory *tint*, will always show absence of detail in the shadows. (Fig. 40). This is, of course, a parallel instance to the harsh contrast obtained when copying a warm brown or red print upon an ordinary plate.

It may be as well to mention that even when panchromatic plates are used, and the resultant negatives need no retouching in the ordinary sense of the term, the work of the artist is not finished. Indeed it is only when the negative is reasonably accurate that the retoucher can do his best work. People with snub noses, large ears, crooked teeth, crow's feet, or gray hairs, do not want to appear as they are, few of us do; but a retoucher should be an artist who improves the picture while preserving the spirit of the likeness, and not a mechanic who has to atone for the faults of the tools.

There is no need to dwell at length upon the effect of orthochromatic rendering upon the clothing of the sitter. To those who have read carefully the earlier portion of this book the advantages will be obvious, and is well shown in Fig. 40. A point which may appeal to the professional photographer is that he will be able to free his sitter from any restraints as to the clothes which shall be worn. It is by no means an infrequent thing for a sitter to have a favourite costume, and to be disappointed at the difficulty which it presents to the operator.

But one point more may be mentioned, those photographers who tint their photographs will find that a panchromatic rendering is of the very greatest importance as enabling them to avoid masses of black where it is most important that they should have little deposit in their print, in order to get bright colors. To get a satisfactory colored reproduction of a scarlet tunic, for instance, it is necessary that the negative shall have a good deposit of silver where the tunic is, so that the color shall not be applied to a mass of black in the print.

Exposure.—The use of filters in portraiture raises obvious difficulties as to exposure. Red sensitive plates can be obtained which are of the same speed as extra rapid plates, quite as fast as those generally used for studio work. For ordinary

purposes, a K1 filter will be deep enough, and this will increase the exposure by half as much again, or if a little more exposure can be afforded, then the K1½, requiring twice normal exposure, will be found the best all-round filter to use. For difficult, badly freckled subjects, or such a case as the scarlet tunic, it will be necessary to use a K2 filter. Here the exposure will be three to four times that to which the worker is accustomed. Each worker will know for himself whether he can manage this. At the same time it may be pointed out that the gain in rendering is so considerable, that it will make the best of any sacrifice of accuracy in the lighting if that cannot be avoided. Photography in ordinary rooms is often made far more difficult by the "unsuitable" color of the surroundings, a difficulty which is, of course, eliminated by truly orthochromatic procedure. Even when the exposure is increased by the use of filters, it will be very much shorter than it was in the early days of photography, when wet plates were used. Then an exposure of five seconds, was considered unusually short, and although we have no wish to return to the days of head-rests, yet, if we except young children, there are few people who cannot keep still in any position suggestive of repose for a much longer period than five seconds.

Artificial Light Sources.—Artificial light sources contain as a rule much more red and green light than daylight. If we have two sources in which the blue-violet portions of the spectrum between 4,000 and 5,000 A.U. are equal in intensity, one being daylight, then, if the other be a tungsten lamp the latter will give out seven times as much green and twenty times as much red light as daylight. Incandescent gas gives about twelve times as much green and from fifteen to twenty times as much red. Arcs used with red or yellow flame carbons are similar to tungsten filament lamps. Open arcs have about one and a half times as much green, twice as much red.

Since we know the relative sensitiveness to blue, green, and red of the plates (Chapter II), we can construct the following approximate table:

Light source compared with daylight, taking amount of blue-violet light as the same in the two sources.

Relative sensitiveness of the two plates as compared with an ordinary plate of the same sensitiveness to daylight.

Light Source	Green Proportion.	Red Proportion.	Sensitiveness of Erythrosine Plate.	Sensitiveness of Wratten Panchromatic Plate.
Acetylene or evacuated tungsten . .	7	20	1½	3
Incandescent gas .	12	20	1¾	4
Gas filled tungsten .	12	15	1¾	3
Open arc . . .	1½	2	1	1½
Flame arc . . .	1½	1¾	1	1⅜

It follows from this that, owing to the great sensitiveness of the panchromatic plate to the yellow artificial light sources, portraiture by their aid becomes easy, and evening portraiture thus becomes quite practicable. Street work at night, and theatre photography, become also much easier if red sensitive plates are used. For incandescent gas no filter is used, the color of the light ensuring sufficient correction, but if arcs are used (with flaming carbons) A K2 filter should be used, owing to the very strong ultra-violet and violet carbon bands which must be absorbed.

The nitrogen filled incandescent electric lamps are exceptionally suited for portraiture, since they enable a much more powerful artifical light to be used without proportionate increase of expense. Their light is whiter than that from the ordinary metallic filament lamp, and very fairly corrected portraits can be taken by the nitrogen tungsten lamp on the Wratten panchromatic plate with the K1½ filter.

If flashlight is used for portraiture, it will be found that better results are obtained on the Wratten panchromatic plate without any filter than are possible on any ordinary plate, and a "K" filter will enable very full correction to be obtained.

The Mercury vapor lamp is not suitable for work with panchromatic plates. It does not emit any appreciable amount of red light, and its value for photographic purposes depends entirely upon the violet light which it gives out.

CHAPTER VIII

LANDSCAPE PHOTOGRAPHY

THE application of the principles, which have been set down in the earlier chapters of this book, to the photography of landscapes, presents difficulties of which most workers are only too well aware. The discussions which follow papers on "Orthochromatism" in photographic societies usually turn on these difficulties, and the variety of conflicting opinions expressed should be sufficient warning to prevent any writer from too dogmatically stating what should be done.

To M. Andre Callier, a Belgian worker who is both a first-rate landscape photographer and a scientific investigator of great knowledge, we are indebted for the framework of this chapter, and for many of the points with which it deals. We are indebted to Dr. E. Deville, Surveyor General, Canada, for the two views in Jasper Park, in the Canadian Rockies.

Landscape photography presents several features which entirely distinguish it from those branches of work with which the rest of this book is concerned. In the first place, landscapes display, as a rule, in northern climates a less marked scale of contrast than the subjects with which we are accustomed to deal in the studio. At the same time, however, the sky is usually of much greater intensity than any other portion of the gradation scale, and it follows that, in order to obtain detail in the shadows (seen by the eye because of the expansion of the iris), it is often necessary to over-expose the sky.

This over-exposure, which destroys differences in intensity which are perceived by the eye (clouds for instance), can be removed by the use of contrast color filters which, by absorbing the sky light, *seem*, in certain cases, to lengthen the scale of intensities which the plate is capable of rendering.

It is desirable to point out that, if such deep filters be employed, it is absolutely necessary that the exposure should be ample.

Insufficient exposure will result in a thin sky in the negative,

Courtesy of Dr. E. Deville

FIG. 41. WRATTEN PANCHROMATIC PLATE WITH "G" FILTER

Courtesy Dr. E. Deville

and in general hardness in the foreground, and the resulting picture will give a general impression of *over-correction.*

True over-correction in landscape work is probably very rare; it may, of course, be caused by the deliberate use of very strong yellow filters (and on this point it may be well to add a reminder that, as explained in Chapter IV, screens which are necessary with a slightly color-sensitive plate may over-correct a panchromatic plate), but as a general rule the appearance of over-correction is caused by under-exposure.

Here it should be pointed out that the factor given by the makers of exposure meters and calculators, in reference to sea and sky subjects and distant landscapes, must be used with caution. Thus it is usually stated that $\frac{1}{10}$ exposure found necessary for average landscape is all that is required for sea and sky, but this is only true when no filter is used; if a filter is put on the lens cutting out all the ultra-violet and some of the violet and blue, it will no longer be true, and a negative made with, say, a factor of $\frac{1}{10}$ will be under-exposed and have the appearance of over-correction. On the other hand, too much exposure may be given, and so the contrast desired entirely flattened out. That is to say, not only should a suitable filter be used, but an exposure be given that is correct for the degree of contrast required.

The aim of many landscape photographers is simply to get the clouds and landscape on the same plate. Comparatively small correction is sufficient to accomplish this, and hence the majority of such photographers use a very light filter, such as the K1, which, with a panchromatic plate, will give enough correction for the purpose given above, and at the same time enable the camera to be used in the hand.

But those workers to whom truth of tone is of the first importance will desire to use filters of greater depth, so that the color values of the foreground shall be correctly translated into monochrome.

Many such workers use comparatively deep filters with plates sensitive to the yellow-green, but not to red, arguing that few landscapes contain red, or even yellow, and that the greens can be satisfactorily rendered by a green sensitive plate. On this point the following quotation from a letter from M. Callier may be of interest:

"It is necessary to insist upon the kind of orthochromatic plates which may be used. In spite of the enormous progress realized by plates of the erythrosine type, such plates show

a grave defect in their lack of sensitiveness near W.L. 5,000" (see fig. 11*b*).

"Usually this defect is not of much importance, but there are certain cases where it becomes a great disadvantage. This is so in landscapes, for example, which contain both open meadows and pine trees. If such subjects are photographed by means of plates of the erythrosine type (especially with a filter, if there is also distance to be rendered), there will be obtained in the negative a greatly exaggerated contrast between the densities of the meadows and of the pine trees. The green reflected by the meadows corresponds to the maximum of sensitiveness of an erythrosine plate, while that coming from the pines falls exactly into the gap of sensitiveness. The only method of obviating this is to use a really compensating filter—that is, a filter which absorbs the violet and ultra-violet, but which also has an absorption about the region 5,600 corresponding to the maximum of sensitiveness of an erythrosine plate. Unfortunately, the increase of exposure required by such a filter is very great.

"From this standpoint the new isocyanine sensitizers represent a great advance over erythrosine, and the fact that the plates so sensitized are also sensitive to the orange and red constitutes a second advantage whenever red enters into a landscape."

An important factor in landscape photography which does not enter into studio work is the presence suspended in the air of water particles which, when of large size, condense into mist. It is well known that, if open landscapes are being photographed, a very slight amount of mist results in flat negatives unless strongly corrected orthochromatic plates be used.

The reason seems to be that the suspended particles of water vapor which are transparent for the longer waves of light, and, therefore, only affect vision slightly, act as a very turbid medium for the deep violet and ultra-violet waves, scattering them, and producing much the effect that would be seen if one were to try and look through a sheet of finely ground glass.

As the water vapor condenses, its selection of the longer wave lengths increases; a fog, for instance, will absorb the blue and green rays from the light of an arc-lamp, but will permit the red to pass in greater measure, so that at a little distance the lamp will appear red.

It seems probable that the *scattering* effect of mist near the

ground is at a maximum in the ultra-violet, and that this *scattering* decreases as we pass towards the red. In addition, when the sky is blue the mist reflects this light, and appears blue from that cause.

In order to remove this increased effect of mist in the negative, as compared with the effect seen by the eye, we must absorb the scattered ultra-violet and violet light before it reaches the plate by means of a filter. It is to be noted that, to be effective, this filter must absorb the ultra-violet as completely as possible, and that filters, such as the Wratten "K" filters, are, therefore, preferable to even much deeper filters made of other yellow dyes which transmit ultra-violet light.

The removal of the scattering effect of mist will progressively increase as we remove the violet, blue, and greenish blue, by means of deeper and deeper filters, so that, if strong, sharp-cut filters be used, the air will appear too transparent—that is, there will be a loss of "atmosphere." It is therefore, important that the filter should be of gradual cut, corresponding in curve to the sensitiveness of the eye, and that sharp-cut, strong filters should be avoided. In telephoto work, however, the mist intervening in the great aerial distances between the lens and the object to be photographed is a very serious and real difficulty, and a strong contrast filter, such as Wratten "G" filter, is a great advantage. Many telephoto workers who are troubled by the flatness and fogginess of their negatives would gain much by the use—first, of a satisfactory lens hood cutting off all light not required; and, secondly, of a strong contrast filter.

In exceptional cases even a red filter may be used with advantage. Thus some photographs have been made of a high building at a distance of about four miles, in which an ordinary plate allowed the mist completely to obliterate it. With the Wratten panchromatic and K3, the building was photographed as the eye saw it, but with the deep red "F" filter it was very much plainer, though, of course, the colors in the foreground and intervening distance were over-corrected. It is sometimes stated that a process plate is better for rendering distance, but there is no advantage in this where the improved rendering is only to be obtained by eliminating the effect of the mist, as the process plate is just as susceptible to the ultra-violet and violet rays scattered by the mist as are other ordinary plates.

It may be repeated that the filter used for telephoto work

must either be plain uncemented gelatine, or must be cemented in the very best optical Flats. The great equivalent focal lengths of the lenses employed will not permit of the use of ordinary filters if the best definition is to be obtained. The most convenient method of fitting the filter is usually as a cap on the back of the negative lens, inside the camera, which position enables one to employ the smallest possible screen.

While dealing with telephoto work, it may be pointed out that most landscape workers could take a hint from the telephotographer with regard to *hoods*.

Modern anastigmatic lens are made to work at such great angles that they are seldom fitted with hoods, and the inevitable result is flatness due to fog, caused by the light scattered in the camera. Landscape workers, who do not, or at any rate should not, employ wide-angle lenses, should fit one or more hoods to their lenses, and they will at once see the gain in their negatives.

Assuming the plate to be properly developed in a safe dark room then flat and foggy negatives are due to:

(1) Scattered light, removed by a proper hood;
(2) Mist, removed by a proper plate and filter;
and rarely (3) Over-exposure.

Mountain work presents a few special difficulties. Great distances are continually occurring in consequence of the purity of atmosphere, and the chief difficulty consists in retaining correct gradation between the sky and the snow-clad peaks outlined against it.

The light of the sky is due to the numberless dust and water particles suspended in the upper air. The greater reflecting power of these small particles for violet and ultra-violet light causes the sky color to be blue, and as we ascend higher into the air the particles decrease in size, and the sky reflection becomes less, so that the color becomes a deep blue, and at very great heights the sky is nearly black. (An alternative suggested by Prof. Spring is possible, namely, that the color of air, and especially the upper air, containing much ozone, is blue, and that the upper air absorbs the red light from the white light reflected from suspended particles.)

If, therefore, a deep or even medium filter is used, it may happen that the sky light may be cut out too completely, and the sky will appear too dark, with the intensely white snow showing in great contrast against it. It is of course true that

this is to a great extent also the effect to the eye, but an entirely truthful rendering may be displeasing when the charm of the sky color is removed, and the effect is certainly exaggerated if the filter used is of too sharp cut.

For ordinary mountain work, a Wratten panchromatic plate with a K1 filter is of sufficient depth to render both sky and pines satisfactorily against the snow, but if there is much color in the near foreground then a K2 may be advisable. For mountain telephoto work, a K2 filter is necessary to remove the haze, a "G" filter being too strong if the distances are free from fog.

The nature of the reflection of the sky also gives us a clue as to the best means of rendering cloud forms. It is clear that the rendering of cloud form depends on causing the cloud to have the maximum effect on the plate when contrasted with the light reflected from the sky. Since the light reflected from the clouds is white, while that from the sky contains a lesser proportion of the longer wave lengths, it is clear that the deeper the filter the greater will be the contrast. Thus the use of an ordinary plate, photographing by means of the ultraviolet and violet light will usually obliterate the contrast, unless the clouds be very strong. Using a panchromatic plate and a K3 filter we shall obtain the same degree of contrast as that which is seen by the eye.

With the strong yellow "G" filter this contrast will be exaggerated, while with the tricolor "A" filter we get a very high degree of contrast, making this filter probably the most useful one for the record of faint cloud forms. By the use of an even deeper filter, such as is obtained by using the "D" and "G" filters together—with a special plate such as the "Wratten spectrum panchromatic"—we can photograph near the limit of the visible red, and owing to the small proportion of this light reflected by the sky, can record wisps of vapor which are barely visible to the eye.

It is quite possible to photograph by means of the infra-red rays, and Professor R.W. Wood, of Johns Hopkins University, has published some remarkable results. For such work we can supply the Wratten infra-red filter as used by Professor Wood. It must be used in conjunction with the Wratten spectrum panchromatic, as the ordinary panchromatic is not sufficiently sensitive to the infra-red. The exposure required on a landscape in bright sunlight will be from two to five minutes.

CHAPTER IX

THE PHOTOGRAPHY OF COLORED OBJECTS FOR REPRODUCTION

THE photographer for reproduction will have many objects to photograph similar to those which have previously been dealt with, and the procedure will, in the main, be similar. It is desirable to consider for what process the negative is required before deciding on its character. If it is to be merely an ordinary photographic copy in monochrome of a colored object, then the usual rules apply. If the negative is required for mechanical printing, then we must know the process, *i.e.*, whether for a surface process, such as lithography and collotype; intaglio, such as photogravure; or relief, such as half-tone, in order to develop to a suitable contrast.

Photography is sometimes brought to the aid of pure chromolithography, when the reproduction is to be of a different size from the original, or if it is framed and cannot be removed from the frame. The first thing necessary in the process is to make a key tracing, which is an outline made on transparent transfer paper, of every patch of color showing variation from the next patch. This has to be transferred on to all the stones used to build up the colored picture in order that the lithographic draughtsman may know exactly where to put his work, so that in the end the "register" or fit of the various colors is perfect. If now a photograph must be used instead of the original itself, it is obvious that a negative must be made which best distinguishes the variations of color, and that the correctness or otherwise of their translation into monochrome is of no importance whatever. The plate used and filter chosen must therefore depend entirely on the character of the subject, having this end in view. Viewing the original through a number of differently colored filters will frequently be of assistance. It will sometimes be found that an ordinary plate, without any filter at all, will distinguish the patches of color better than any other procedure. With regard to collotype

and photogravure, which require ordinary negatives, color sensitive plates with contrast or compensating filters should be used, as the particular subject requires.

With regard to photo-lithography and relief processes, such as ordinary half-tone, in which the final result is to be a surface broken up into grain, the grain is nearly always required in the negative from which the copying on to the printing surface is done. Consequently it is an economy if the negative, which gives us the color record, can also be split up into grain at the same time. To work in this manner is called the "direct method," and the Wratten process panchromatic plates are specially designed for the purpose. Whether it is possible to work "direct" or not depends on the amount of contrast contained in the original.

In a grained negative the illusion of tone is secured, not by varying density (*i.e.*, thickness of deposit of silver) as in an ordinary continuous tone negative, but by deposits of silver in the form of spots of very great opacity, but of varying size. Places where the spots are very small and there is much clear glass will represent shadow, those where the spots are very large and there is little clear glass will represent the high lights, and proportionately for other tones; the size of the dots everywhere corresponding with the amount of light reflected from the original. Except in certain cases, when the so-called "highlight" negatives are required, any given area in the highlights must contain some transparent spaces, and in the shadows must contain some points of dense silver. But it is obvious that, if there is a considerable amount of contrast, it will be impossible to fulfil the necessary conditions, because before any points of silver have impressed themselves in the shadows of the negative, the dots in the highlights will have received so much exposure as to make them completely cover up all the transparent spaces, and that part will no longer serve as a grained negative. So that only certain objects or originals are suitable for reproduction by the "direct" manner, which consists in placing the object in front of the camera, illuminating it, and photographing with the half-tone cross line or irregular grain screen in front of the plate. The actual details of this work would be out of place here; further details can be obtained from our booklet on "Reproduction Work with Dry Plates." It may, however, be well to point out that originals with heavier contrasts than about sixteen to one should not be attempted by the "direct" process; that is,

if the light reflected from the shadows is taken as one, then that reflected from the highlights should not be more than sixteen times as much. It is true that heavier contrasts are often done, and made to pass by the waving of white paper in front of the original during the exposure, a practice known technically as "flashing," but, beyond a small amount, this practice is very strongly to be deprecated, as it is ruinous to detail and gradation, and plates and filters must not be blamed if the results appear flat and unsharp when this is done.

With subjects of heavy contrast, resort must be had to the "indirect" process. In this a negative is made in the ordinary way, but the exposure and development are so arranged that, while all the detail is secured, the density of silver deposit is restricted, so that the negative does not exceed a certain range of contrast. From the negative a positive is made, either on paper or, preferably, on a slow dry plate (*i.e.*, a transparency). This, while having all the details of the original, will have the contrasts compressed so that they are within the limits possible to the half-tone process, and a grained negative can now easily be made in the usual manner, either on wet collodion or on another dry plate.

As examples of common subjects having heavy contrasts, we may take most solid objects such as articles of furniture, carpets, etc.; though some articles for catalogue illustration, such, for instance, as candy or various packet goods, may very well be done direct. Many oil paintings, especially old ones, are better reproduced by the indirect process.

The next thing to be considered is the style of reproduction. If for monochrome printing, then the principles already outlined in previous chapters must be applied. If color contrast is required, then a filter must be used absorbing that color which it is appropriate to render darkest, and a plate sensitive to the colors that are not required to print. If, on the other hand, correct luminosity values are wanted, then a K2 or K3 filter should be used with a Wratten panchromatic plate. In general it will be found that, for color work in a reproduction studio, the panchromatic plate will be most suitable; for "direct" grain negatives, the Wratten process panchromatic.

In the case of an original, such as a brown or sepia print, that by reason of its color is difficult or impossible to do on an ordinary or wet collodion plate, it is generally sufficient to use a Wratten panchromatic or process panchromatic plate

without any filter; though to secure the utmost possible detail it may sometimes be necessary to use a K1 filter.

The simplest cases of color reproduction are presented by stained MSS., typewriting, checks, maps, and so forth. These nearly all require the use of contrast filters. A full discussion on the correct procedure will be found in Chapter VI.

Next come subjects to be reproduced in two colors. Sometimes these are drawn in two colors, sometimes in more; in either case it is desirable to know what colored inks are to be used in the reproduction. Filters are then selected so that the light reflected from the parts of the original which it is desired to print in one of the inks shall be absorbed and the negative be transparent there. Thus, supposing we have a crayon drawing of a lady's head in pink and yellow, we want a green filter to absorb the pink and allow the yellow to pass, and a blue-violet to pass the pink and absorb the yellow. Many good color-effects may be obtained in two printings when the two inks together make a black. Any two inks of color complementary to each other will give a black and a scale of grays, as well as the two colors separately. Thus, an orange-red and a greenish-blue will give those two colors and black; a green and pink, the same; an ultramarine blue and yellow the same. This method can be applied, also, when we only have one color and black; for example, a red and black. The use of the red filter, "A," and a panchromatic plate will permit only the black to be photographed; the second negative is made with the blue filter, and will give us both the red and black. Now if this be printed in an ink imitating the red of the drawing, the black can be printed in black, or in an ink which on the top of the red will make a black.

Another method is to make a positive from the negative taken through the red filter; now register upon this the negative taken through the blue filter. This latter negative records both blacks and reds as clear spaces, while the positive records only reds as clear spaces, so that the two together are equivalent to a negative, in which the red of the subject is represented by clear spaces. The black negatives, is of course, taken through the red filter. If we have several colors and black the procedure is more difficult, and it is sometimes troublesome to extract the black if the colors are at all dark. A filter should be selected that does not completely cut out any color present, but that transmits most freely the deepest color. Sometimes it is most convenient to expose the same

plate for a portion of the time through each of the filters of a tricolor set, but the filters have to be made with best optically worked glass, as otherwise the resulting image will appear doubled. Sometimes, on the other hand, no filter at all is necessary, or at most a light yellow filter, and a sufficiently long exposure will give the black alone on the negative.

It is unnecessary to deal with the three-color process here, as a separate chapter is devoted to that, and the methods are exactly the same in a reproduction studio, except that arc lamps are frequently substituted for daylight. These, however, of whatever type, do not cause any other adjustment than corrections in the exposure ratio of the filters, which will not be the same as for daylight.

It is yet far from being realized how much help could be obtained from intelligent photography in photo-lithography, for the use of the camera, with suitable plates and filters, could save much of the lithographic draughtsman's work. We have seen beautiful reproductions of water-colors by photo-lithography where the lithographer has had a photographic basis on the stone, and these were produced in days, when without the photographic work weeks would have been required. Though these reproductions have been made in from five to ten printings, the perfection of the plates and filters now obtainable, if used with knowledge, would enable excellent reproductions to be made with very few printings, and this question is worthy of the serious attention of all chromo-lithographers.

CHAPTER X

THREE-COLOR PHOTOGRAPHY

(1) *The Additive Process*

THREE-COLOR photography is based on the fact, first discovered by Clerk Maxwell in 1860, that all colors can be matched by a mixture of three primary colors—a red, a pure green, and a blue—if the proportion of these constituent colors be rightly chosen. By an apparatus which he termed the "Color Box," Maxwell determined the exact position in the spectrum of these three primary colors, and also the proportion in which, at each point of the spectrum, they must be mixed in order to reproduce to the eye the sensation produced by the light of the spectrum itself. The intensities of the primaries at each point form three overlapping special curves, which are shown in fig. 43. If, now, we construct a set of three filters which, when used with a suitable plate, will give these curves, we can obtain in the spectrograph a set of negatives in which the opacities at every point of the spectrum are proportional to the light intensities for each primary. If we make from these negatives transparencies, and project the three transparencies so that they converge upon one screen by means of approximately monochromatic lights exactly corresponding with the primaries, we shall reproduce the spectrum; or rather, we *should* reproduce the spectrum if our plates would rigidly translate light intensity into the equivalent opacity. This they will not quite do; at the same time the reproduction is very good. This result, however, can only be obtained if the correct exposure is given to the spectrum. If a number of varying exposures to the spectrum be given, it will be found that the reproduction will vary, not in intensity only, but also in color. The reason can easily be seen by referring to the diagram (fig. 43) showing the curves of the filters. Take, for instance, the point 6,100, which should be recorded to a certain extent in the red filter, and to about ⅓ of this extent in the green filter, and should therefore be

reproduced by the whole of the red light, and by ⅓ of the green, thus appearing orange. With the shortest exposure, however, this will record only in the red filter, and not at all in the green, that is; it will be projected as a faint but pure red. On the other hand, with great exposure the plate will be quite opaque in both the red and the green negatives, and in reproduction we shall have a bright yellow caused by the mixture of all the red with all the green. The same is true of nearly all points in the spectrum. With over-exposure the region about 5,200, for instance, which should be pure green, will be re-

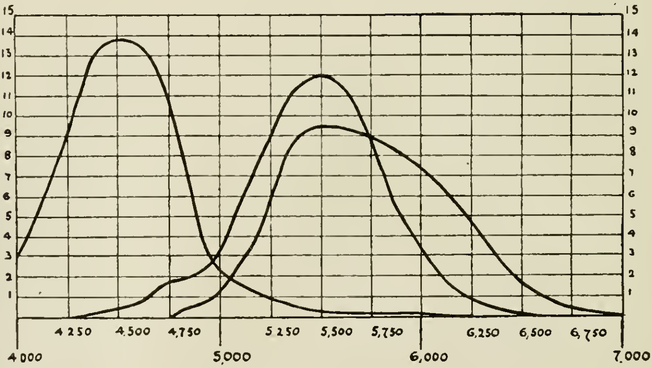


FIG 43. TRICOLOR SENSATION CURVES

corded to some extent in all three filters, and will reproduce as a greenish white. This variation of color with exposure is of great importance in practical photography, as whatever variation there is in intensity, the true *hue* must always be reproduced. It is consequently necessary that the absorption curves of the filters should be as abrupt as possible, and, as a matter of fact, suitable filters are shown in fig. 44.

Such filters will not satisfactorily reproduce the spectrum; they will divide it into five sharp and abrupt regions. First, the region extending down to 6,000, which has been recorded in the red filter only, and which is therefore reproduced as pure red. Secondly, the narrow region between 5,900 and 6,000 which has been recorded through both the red and the green filters, and which, therefore, reproduces as a mixture of red and green light, that is, as yellow. Thirdly, the region between 5,900 and 5,000, which is recorded only in the green

filter, and reproduces as green. Fourthly, the region between 4,800 and 5,000 recorded in both the green and blue filters, and reproduced as blue-green. Fifthly, the region between 4,800 and 4,000, recorded only in the blue filter, and reproduced as blue.

It will be noticed that this failure is only in the reproduction of pure colors other than the projecting colors themselves and their simple mixtures. In natural objects such pure colors do not occur. In the spectrum, for instance, a green of wave length 5,600 is a yellowish green, while a green of wave length 5,200 is a bluish green. Both will reproduce alike with sharp-cut filters, since both will be recorded only in the green filter. The yellowish green of any object will, however, be recorded fully in the green filter, and to a less extent in the red filter, while it will only record to a very slight extent in the blue filter. It will, therefore, reproduce as a yellowish green. A

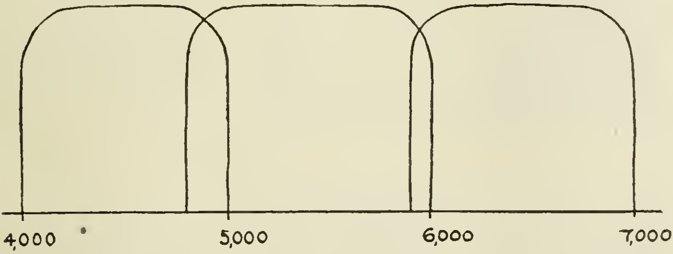


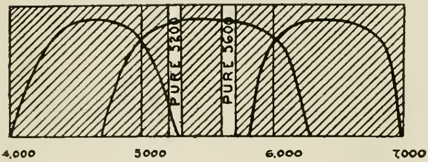
FIG. 44. THEORETICAL TRICOLOR FILTERS

natural blue-green, on the other hand, will be recorded to but a very small extent through the red filter, and to a much larger extent through the blue filter, so that it will reproduce as a blue-green. The illustrations show the absorption curves of dyes made up to match exactly to the eye the spectral regions (fig. 45).

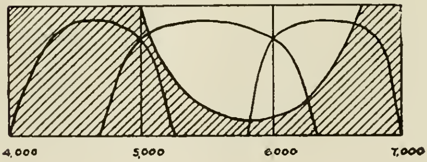
The transparencies made from the negatives taken through the three filters can be projected, either by means of a triple lantern or by such a device as the photochromoscope. The filters to be used for projection are somewhat different both from the taking filters and also from the original narrow bands which we have hitherto assumed.

In projection with the triple lantern, especially, the great difficulty is to obtain sufficient light, and this difficulty at once prohibits any approach to monochromatic illumination.

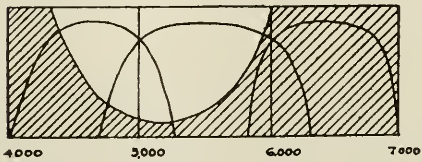
In order to get bright colors, it is necessary that the absorptions of the projecting filters should be abrupt, and that they should not appreciably overlap one another. Inasmuch as the taking filters do somewhat overlap, it is better to use a different set for purposes of projection. The red projecting filter should be a true, strong red, not an orange— that is to say, it must not pass any light of shorter wave length than 6,000



SPECTRUM SHOWING PURE COLORS WITH TRACE OF FILTER CURVES.



CURVE OF NATURAL YELLOW-GREEN MATCHING PURE LIGHT OF W.L. 5,600



CURVE OF NATURAL BLUE-GREEN MATCHING PURE LIGHT OF W.L. 5,200

FIG. 45

A.U. The green should be a pure green, not transmitting any blue, and extending from 6,000 to 5,000 A.U. It would seem that the taking blue filter should be suitable also for projecting; if, however, the triple lantern be set up, and the above-described red and green filters be used, together with standard blue, it will probably be found that the field is yellow. This is due to the fact that dyes absorb some of the light which they are supposed to transmit, and the proportion which they absorb depends on the dye (see Chapter I). Owing to the fact that absorption bands are nearly always sharper towards the red end of the spectrum than towards

the blue end, a red filter will absorb very little red light. Our red filter absorbs, at 5,400, 16 per cent. of the incident light. A green filter absorbs much more green light; at 5,900 our green filter absorbs 74.3 per cent., transmitting only about a quarter. At 5,400 it transmits about half the incident light. But a blue filter absorbs very much blue light. At 4,800 our blue filter transmits about one-fifth of the light, and the same proportion at 4,500. This absorption of useful light by the blue filter is not a disadvantage in photographic work, because, even with the best red-sensitive plates, the exposure through the red filter is greater than that through the blue filter, and if the blue filter were lighter, the effect on the total exposure would be inconsiderable, while the exposure through the blue filter would be so short that it would be more difficult to give it accurately. But this absorption of the blue light by the blue filter is a serious disadvantage if the filter is used in tricolor projection and it is therefore necessary to use the brightest blue filter which can be obtained.

This additive synthesis, as it is called, by means of a photochromoscope or triple lantern, is much the easiest process of three-color photography to work, and gives also the best and most accurate reproduction of colored objects. A modification which has been greatly developed is the screen-plate method of color photography. In this method, suggested by Ducos du Hauron, and first carried out by Joly, a glass plate is divided into a number of colored elements, these elements being so small that they are indistinguishable to the eye, and being colored with the three primary screen colors, so that the plate as a whole appears to be gray. Such a plate is put with the elements in contact with the film of a panchromatic plate, which has been so adjusted to the screen, either by means of modification in the making of a plate or by a compensating filter, that white light produces equal effect through each of the three-color elements.

If a negative of a colored object be taken on the plate through such a screen, and a positive be made from the negative, this positive being registered again upon the same screen, we shall obtain a reproduction of the colored object by additive synthesis.

Thus, in the diagram, fig. 46, we have three patches of red, green, and yellow light falling upon the screen, which is represented only by three unit elements. The red light penetrates the red elements, producing blackness in the negative film

beneath them. The green light penetrates the green elements, producing blackness in the film beneath them. The yellow light, composed, of course, of a mixture of red light and green light, penetrates both these elements, leaving the negative film transparent only under the blue elements.

When the positive is registered again upon the screen, the red light is represented by the clear red elements, the green and blue ones being obstructed. In the same way the green is represented by clear green elements, the red and blue being

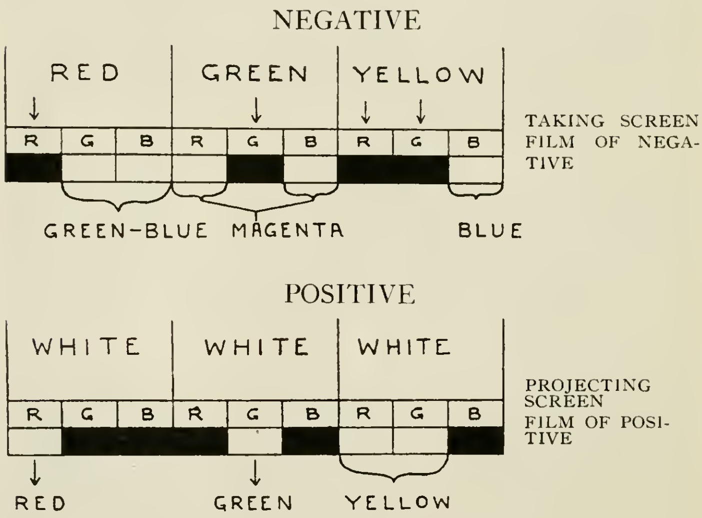


Fig. 46

obstructed, and the yellow is represented by the light coming from the mixed red and green elements, the blue only being obstructed. It will be seen that if the negative instead of the positive be registered upon the screen, the complimentaries to the original colors will be obtained; the red will be represented by a mixture of green and blue, the green by the magenta color resulting by mixing the red and blue, and the yellow by blue.

Professor Joly, who used exactly the method described, made his taking screen of wide-banded colors somewhat resembling the color mixture curves, while the viewing screen on which the positive was registered had deep narrow-banded colors.

The Autochrome plate, on the other hand, is not worked in quite the same way. The color elements in this are very small, being composed of flattened starch grains, and the emulsion is coated on the plates. After exposure and development the image in the emulsion is reversed so that it is converted into a positive and the colors can be seen at once.

This necessitates the use of the same filters for taking and viewing, these filters dividing the spectrum almost exactly into three equal parts. The exactness of color-representation of the Autochrome Plate would seem to justify such a procedure, though undoubtedly pure deep reds would be better rendered, if a less orange-red could be used for the viewing filter.

There are many systems of screen-plate photography, all similar in principle either to the Autochrome or the Joly method; For practical instruction there are one or two excellent handbooks and numberless articles dealing with the matter.

(2) *The Subtractive Process*

The Additive methods of Synthesis give results of great accuracy and are very easy to work, but there are several defects connected with them Probably the greatest is the difficulty of obtaining bright pictures.

The triple lantern is wasteful of light, and is also a very expensive piece of apparatus. Screen plates can, at best, only give one-third of the brightness which should be given by their whole surface, and they therefore require powerful light sources to show them satisfactorily. Another defect is that the additive processes cannot give paper prints, at any rate as yet. For these reasons the subtractive processes are of more practical importance than the additive, and though the introduction of commercial screen-plates has greatly increased the use of additive methods, the fact that the subtractive process is used in commercial three-color half-tone work makes it much the most widely used method.

In subtractive processes the three negatives, through the red, green, and blue filters, are taken as in the additive process, but they are printed, not as transparencies to be projected by colored light, but as three superposed prints, each print being made in a color which is complementary to that of the taking filter.

Thus, if we divide the spectrum so that we consider white light to be made up of red, green, and blue, then the negative

taken by red light is printed in a color which transmits or reflects all the green and all the blue, simply absorbing the red. In the same way the negative taken by green light is printed in a magenta color, which transmits all the red and all the blue, absorbing the green. The negative taken by blue light is printed in yellow, which transmits all the red and all the green, but absorbs the blue. Let us turn now to the fig. 47, which shows six patches of color consisting in the top line of red, green, and blue, and in the bottom of their complementaries, blue-green, magenta, and yellow. In the red negative we shall record as black the red patch, and also the magenta and yellow patches, by virtue of the red light reflected from them. If we print this in a blue-green ink we shall print blue-green wherever there was no red in the original; that is to say, in the position of the green patch, the pure blue patch, and the blue-green or minus red patch.

The green negative will record as black the green patch, and the blue-green and yellow patches by virtue of the green light reflected from them. Printing it in magenta we shall print magenta ink in the positions of the red patch, the pure blue patch, and the magenta patch, these being the patches from which no green light was reflected. In the same way the blue filter negative will record as black those patches which blue light is reflected; that is, the blue patches, and the magenta and blue-green patches. This is printed in yellow ink, so that we print yellow in the places where no blue is reflected; that is, in the positions of the red patch, the green patch, and the yellow patch. Superposing these three printings, as is done in the original figure, we obtain red by the printing of magenta ink upon yellow ink, green by the printing of the blue-green ink on the yellow ink, and blue by the printing of the blue-green ink upon the magenta ink, the other three patches being produced by the printing of the three inks separately. If we print all three inks on the top of one another we shall get a black, or if they are only partially printed a scale of grays. Of the various methods for actually preparing photographic lantern slides or prints in the three-color process it is not intended to speak in this book; for that purpose reference should be made to a book on three-color photography, such as Dr. Koenig's book on "Natural Color Photography," translated E. J. Wall, but it is necessary to discuss the filters, plates, and printing colors.

The question as to the filters to be used in the subtractive

Print from Blue Filter Negative

Print from Green Filter Negative

Print from Red Filter Negative

Fig. 47

process, with especial reference to half-tone work, was investigated by A. J. Newton and A. J. Bull.

They came to the following conclusions:

1. It is not possible, nor is it desirable, for any filter and plate to follow either the color sensation, color mixture, or certain other calculated curves.

2. The effect of using plates having maxima, with broad-banded weak filters, is to cause a degradation of any pure color occurring in the band of insensibility; therefore plates showing gaps in the spectrum record (erythrosine plates, *e.g.*) should not be used for the green negative.

3. Ultra-violet should not be recorded, as it will exercise a disturbing effect where it is recorded by colors other than blues and violets, as is the case with some browns, scarlets, and yellows, these reproducing with a distinct bluish tint.

4. As much red should be recorded as possible.

5. There should be no unrecorded gaps in the visible spectrum, for while these may not be important for certain mixed colors of pale tints, they are fatal to correct rendering of colors, the spectra of which do not extend beyond the gap.

6. We think that we have proved that the filter records should be even, end abruptly, and overlap each other as follows: the blue-violet and the green should overlap from 4,600 as far as 5,000, and the red and green should overlap from 5,800 to 6,000.

These recommendations as to the filter transmissions appear to be sound, and form a sort of mean to the practice of various workers. The crux of the whole matter lies in the question of the green filter. According to the theory of the subtractive process, pure blues are produced by the printing of magenta on blue-green, the absorption of the green leaving blue. Unfortunately most magenta inks, and indeed most dyes, absorb far too much blue, and when printed on blue-green they leave only a very dark and violet-blue.

In order to avoid this it is desirable to prevent full-strength magenta being printed on the blue-green by recording the blue to some extent in the green filter negative. Unfortunately the extension of the green filter, in order to allow this, involves a difficulty with green, and especially with dark and yellow greens.

The exposure which is given to the green filter is regulated, not by the light reflected from *greens*, but by the light reflected from *white* objects.

Now, as has been shown in Chapter I, green objects show a considerable absorption of the green light itself, and consequently if the green filter is broader than their region of strong reflection, green objects will appear very dark and be much under-exposed. The result of this will be that some magenta will be printed on the greens. Moreover, the blue-green ink or dye very rarely contains sufficient green, so that greens are usually too dark, and the effect of the printing of a small quantity of magenta is very serious.

It is necessary to compromise, and probably the best effect is got by a green filter which is somewhat narrower than that suggested by Newton and Bull. The Wratten tricolor green filter extends from 6,000 to 4,800. With modern red-sensitive plates it is necessary that the green filter should not have any appreciable extension into the red. Red colors are usually very luminous, absorbing little red light, and if they are transmitted by the green filters they will record, preventing the printing of sufficient magenta, and making the resulting color too orange.

This great luminosity of red color is probably the explanation of that somewhat puzzling phenomenon, the success of the three-color process before the use of plates really sensitive to red light.

It was shown by Dr. Sheppard and Dr. Mees that more than half the record through many red filters upon the plates then in use was made by waves of less length than 6,000 A.U. But pure reds are so luminous, even near their absorption band, that they are capable of recording sufficiently by such rays alone.

It has often been suggested that the blue filter should transmit some of the extreme red. Many such filters are in existence and it has been said that the use of such filters represents a departure of sound practice from "theory." The cause of the existence of such filters is, undoubtedly, that it is difficult to make a bright blue filter in which the red is completely absorbed.

But as to the "sound practice" it must be explained that until pinacyanol came into use there were *no* plates which recorded the extreme red transmitted by these filters, and consequently it was simply of no importance.

Even a filter made of methyl-violet, which appears quite purple by daylight and bright red by gaslight, gives *no* red record at all on a pinachrome plate, while on a *pinacyanol*

bathed plate the effect of the spectrum of daylight is about nine times as great at the blue end as at the red.

If, however, a filter such as rhodamine, which transmits all the red and orange, be used with a Wratten panchromatic plate, the effect will be that a scarlet color will register in the blue-filter negative as well as in the red, and consequently will be represented by magenta printed alone With such a filter bright yellow will record in all three negatives, and be left as white in the print.

For these reasons there is no doubt that the blue filter should not record any red whatever.

It is of great importance in three-color work that the three negatives should be of the same gradation as nearly as possible. Should this not be so, a scale of grays produced by the superposition of three printings will differ in color at the two ends. Such a scale may, for instance, have the lighter tones of a bluish tint, while the deep tones are brownish. In order that the three negatives should be identical in steepness of gradation, it is necessary that they should all three be made on exactly the same kind of plate. Plates vary considerably in the rate at which they develop, this rate varying in two consecutive batches of plates made in the same way. Consequently, if the three negatives be made on three different kinds of plate, even if these be simply the same plate bathed in different dyes, the rates of development are unlikely to be the same, and the gradations will be different to some extent.

It was formerly customary to use three kinds of plate sensitized for the special spectral regions transmitted by each filter. This was necessary because only in this way could the shortest possible exposure under each filter be obtained. With the introduction of the satisfactory Wratten panchromatic plates sensitive to the whole spectrum, this reason has disappeared, and it is now certainly the best practice to use the same panchromatic plate for all three exposures. Such a panchromatic plate, however, necessitates the employment of filters which cut accurately at the required points. As pointed out above, a red transmission band through the blue filter is of no importance if the plate employed be not sensitive to red, but if a panchromatic plate be used, the blue filter must rigidly cut out red light.

Mr. Chapman Jones and Sir William Abney have shown that light of various colors does not produce the same gradation upon photographic plates. Experiments by E. Stenger

show that the same statement is to a less extent true of plates sensitized with the isocyanine dyes.

A large number of measurements of the Wratten panchromatic plate, when exposed through the three filters used in tricolor photography, have been made, and they show that the variation in gradation between the three curves is inappreciable, being very much less than in erythrosine plates, or even plates sensitized with any single dye. Consequently, it may be safely assumed that if the three negatives are made on the same plate or on three plates from the same box, and are developed together, the gradation of the three negatives will be identical.

In order to help in this matter, the Wratten copyboard chart was put on the market. This contains a neutral gray graded strip going by steps from black to white. This strip should be rendered by equal density in all three negatives (and will be) if the exposure is correct, and the development the same. The chart also contains marks to make register easy, and three color patches which enable the respective negatives to be immediately identified.

The real difficulty of the subtractive processes lies in the selection of the printing colors.

These printing colors, by whatever method they are to be applied, whether as stained gelatine, in the stripping film or other carbon processes, as dyes, in the pinatype process, or as printing inks, must be, as nearly as possible, complimentary to the taking filters. The reason being that we start with the assumption that the paper on which we print (or the viewing surface, if transparencies are in question) is reflecting blue, green, and red, comprising all colors, which, when blended together, look white. Now, as already stated above, if we print from the red record negative, we are printing from the shadow portions of the negative, that is where there was an absence of red in the original and therefore no record, so that we must print in a color that completely absorbs all red. At the same time, there may have been some other color in this portion of the original, so that not only must the red be absorbed, but the green and blue must be completely reflected. Therefore this color will be a minus-red (blue-green). In the same way the material in which the shadows of the green record negative should be printed will be a minus-green (magenta), which entirely absorbs the green and reflects all the blue and red, and the blue record negative must be

printed in a minus-blue (yellow), which entirely absorbs the blue, and, at the same time, completely reflects the red and green.

Although it is not yet possible, and perhaps never will be, to obtain perfect printing colors, we know what is the ideal, and we can therefore see what defects will usually occur. Shortly stated, the main trouble is that they do not sufficiently absorb the colors they should absorb, and do not reflect sufficiently the colors they should reflect. Although yellow is generally the most satisfactory of the three, it reflects nearly 10 per cent. of the blue and violet it should completely absorb, and it absorbs about the same amount of the colors it should reflect entirely. The red (magenta) printing color which should absorb all the green and reflect all the blue and red, does not absorb completely the wave-lengths represented by the filter records; in parts there is a reflection of 20 per cent., and even in the colors that are best absorbed there is still some reflection. The colors that should be entirely reflected are worse, since from 25 per cent. to 60 per cent. of each of these colors is absorbed, instead of being reflected, blues and violets being very imperfectly reflected. The blue printing color is worse still; it absorbs from 50 per cent. to 60 per cent. of its own brightest color, nor does it absorb the red completely.

Now we can see from this that we must expect to find defects in the color rendering, even when the filters and plates are perfect, and exposure, development, and printing have been quite correct, and further consideration will show what sort of errors to expect.

A red must be reproduced by printing full strength yellow and full strength magenta. Now the yellow allows some of the blue to be reflected, and the magenta allows so much of the yellow and yellow-green to be reflected, that the result will be a grayish orange rather than a true red.

Yellow will be reproduced by yellow alone. This will be fairly satisfactory, except that there is some degradation due to the absorption of red and yellow and the reflection of some blue, these defects making the color somewhat grayer than it should be.

Green will be reproduced by printing full strength yellow and full strength blue. But some of the green is absorbed by the yellow ink and a much larger amount by the blue ink, therefore the green will look a dark yellowish-green, rather than a bright pure green.

A blue-green will be matched by the printing color itself, but this will be darker than it ought to be, because it absorbs over half of its own color instead of reflecting all.

A pure blue will be reproduced by full strength blue and full strength magenta, but this is degraded, because neither of the pigments reflect all the blue as they should.

Black will not be a dense neutral black, but either greenish black or reddish black, according to whether the red has insufficiently absorbed the green, or the blue has insufficiently absorbed the red.

Because certain colors do not reproduce so well as desired, it is customary to blame either the plates, or filters, or both, or to say that something is wrong with the theory underlying the process. But this is not the case; it is a sufficient proof that the theory is correct and that the plates and filters are suitable, to cite the results obtained by an additive process (as Kromscop or screen plate processes) which gives results that are marvelous in their approximation to the truth.

Attention is often called to greens, and it is pointed out that greens seldom have a dense deposit on the negative taken under the green filter, and therefore the plate is insufficiently green sensitive. This, however, is not the case, the plate being perfectly sensitive to green light, but the reason is that only a small proportion of pure green light is reflected from any green object. Thus, measurements made by A. J. Bull proved that in the case of fir, holly, and ivy, the maximum amount of green reflected was only 8 per cent., 11 per cent., and 12 per cent. respectively, of the amount falling upon them, while even young beech leaves, which are so bright in the spring, reflect only 32 per cent. Two greens taken from water-color sketches reflected only 30 per cent. and 48 per cent., and a very lightly printed emerald green printing ink reflected only 72 per cent. of green, while at the same time reflecting a considerable amount of blue and red. Mr. Bull states therefore that "it is quite proper that common greens should not be recorded by full density on the photographic plate.

"If we now consider in what manner a green is reproduced by the three-color process, we find that a green is only photographically recorded in the green negative (red printing plate), the other two negatives treating it as a black. The green is therefore primarily rendered by the superposition of the printing inks used for the red and blue negatives, namely,

blue ink and yellow ink, and in addition there is printed an amount of red, or rather magenta, ink, which is smaller in proportion as the green subject has been photographed in the green negative. But, as we have seen, the amount of green light reflected by green objects rarely approaches the amount of green light reflected by a white, and it therefore follows that there must always be some considerable amount of magenta ink printing on the greens in order to render them accurately were the process correct.

"This is an inherent part of the process and would present no difficulty if the superposed blue and yellow inks produced a green which reflected practically all the green light which fell upon it, but this, unfortunately, is not the case; the combination of the available yellow and blue inks produces a somewhat dark green, and the crimson degrades it still more. This is the chief cause which tends to mar the mechanical reproduction of greens.

Another defect of which complaint is made is that there is too much yellow in the violets and that therefore the blue filter must be wrong. This, however, is also erroneous, and the fault is again due to the inks. Some yellow would be necessary if the inks were correct, otherwise the blue-green and magenta inks would give only some shades of pure blue. In any case it is not possible to make a filter that will transmit more violet, as will easily be seen if a photograph is made with the blue filter and without any filter at all. The amount of violet recorded will be as great as it is even with no filter, whereas the pale greens and yellows which are stopped by the filter will be recorded when none is used.

The practical importance of the colors of the inks used for tricolor printing has caused us to offer two devices to aid in the selection of these inks, namely, the Wratten Ink Tester for the visual examination of the colors of commercial printing inks, and also the Wratten Ink Control, a set of tricolor blocks, which enables engravers and printers to make a definite practical test.

CHAPTER XI

THE OPTICAL PROPERTIES OF FILTERS

IT is curious to note that in books dealing with photographic optics, and indeed in practically all photographic literature, the optical properties of filters are ignored. In spite of the immense amount of attention which has been devoted to attaining the wonderful definition given by the modern anastigmatic lens, we know of no mention of the fairly obvious fact that the definition of any lens can be completely ruined by a bad filter, and that a considerable number of filters do actually degrade the definition of the lenses with which they are used.

It is frequently stated in photographic periodicals that a simple and cheap way of preparing a filter is to dye a fixed out lantern plate and, after drying, use it as a filter on a portrait lens. While this process is simple and cheap the loss of definition is so serious that probably few careful workers would be satisfied with such a makeshift.

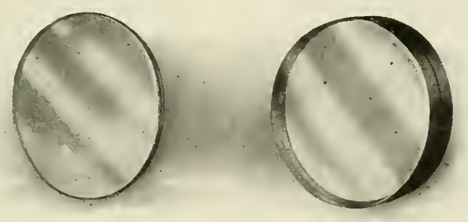
In order to investigate the optical properties of filters, Wratten and Wainwright erected a large testing instrument, consisting of a lens of great focal length forming an image of a distant object, which image can be examined by means of an eye-piece sliding upon an optical bench. The filter to be tested is placed upon the front of the lens and the aberrations which it introduces in the image are determined. The aberrations introduced by a filter will vary as the square of the focal length of the lens, so that as the focal length of the lens is about five feet, and the magnifying power of the eye-piece is fourteen, the linear size of the aberrations is 1,400 times as great as those which the filter would produce upon a lens of six inch focus. An improved instrument of this type has been installed by the Eastman Kodak Company at Rochester.

The errors introduced by any filter can thus be rigidly determined, and, provided that the lens with which it is to be used is known, it is possible to ensure that the filter is quite suitable for its purpose.

Errors in filters tending to produce aberrations and imper-

fect definition are of two kinds; those inherent in the glass, and those produced by strains induced in manufacture or mounting.

The first class of errors can only be avoided by careful selection of the glass, though, unfortunately in this, as in all other optical work, accuracy involves expense. Crystal plate is not good enough in surface for the preparation of filters, and even filters for small lenses require to be made from glass of considerably higher quality. If filters of the highest possible accuracy are to be obtained, then the glasses into which they are cemented should be optically surfaced and tested in the same way as lenses. When filters are intended for microscopic work, or for other purposes where they are not to be used upon a lens, as, for instance, in spectroscopy, it is not necessary for the figure of the glass to be perfect, provided that the



In "B" Glass In "A" Glass (Flats)
FIG. 48. CEMENTED "K" FILTERS

glass is free from surface imperfections, reasonably flat as flat as a good patent plate, for instance, and preferably white optical glass, not green glass.

The Eastman Kodak Company prepare filters in glass of two qualities:

A. Optical Flats, accurately surfaced by the finest optical glass workers and which necessarily makes this glass much more expensive.
B. Picked optical glass for use on lenses, and not recommended for use on lenses of longer than ten inches focal length.

The second class of error is produced by strains to which the glass is subjected. Many filters are made by coating dyed

gelatine upon glass, but this method has the disadvantage that the drying of the gelatine bends the glass into a saucer shape. If then the second coated glass is cemented to the first by Canada balsam, a lens is produced, which may seriously alter the focus of the lens (this is shown with the effect exaggerated in fig. 49), while any greater bending in one direction than in the other will destroy the definition by introducing astigmatism. In order to avoid this defect filters may be made by coating dyed gelatine upon prepared plate glass, and then, after drying, stripping the gelatine from the glass. These gelatine films can be sold at low prices as "film filters," and when handled with care they are perfectly satisfactory. While it is to be recommended that for permanent use cemented filters should be employed, because the film filters deteriorate, yet the latter are convenient for experimental work, and give results equal as far as color correction goes to the cemented filters. No attempt should be made, for photographic work, to protect the films by binding them between cover glasses, because, even if the cover glasses themselves are quite free from any tendency to introduce aberrations, the uncemented films thus bound up introduce complex reflection effects which greatly affect the definition.

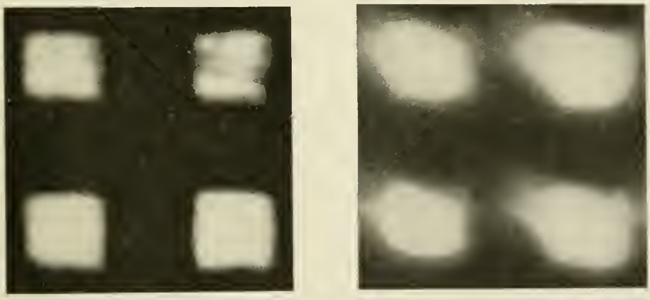
FIG. 49
LENS-SHAPED FILTERS, PRODUCED BY COATED GLASS

A very important point in the preparation of color filters is to ensure that all the filters of a special kind which are prepared are accurately of the same depth of color. The Wratten film filters are tested in the following manner: after a quantity of film has been coated and stripped, specimens are selected at random and are compared with a standard piece of film upon a very accuarte measuring instrument called a spectrophotometer. This instrument indicates whether the tint of the batch is identical with that of the standard, and whether the depth of the tint is also normal. Every sheet of film is then compared visually in four positions with a sheet of standard film in a specially designed comparator instrument, and any sheet which departs by more than a given amount (usually 2 per cent.) from the standard is rejected. The rejections are very considerable, because even with the greatest care variations in the gelatine or in the rate of drying will produce alterations in the color of

the resultant filters, and often batches are rejected altogether, while even of a first-rate batch many sheets will depart too widely from the standard; but the method ensures that all the films actually passed are of the same color.

After cementing the films into selected glass by means of Canada balsam the filters are dried for from three to six weeks according to size at a constant temperature in a special drying cupboard. This slow drying is necessary to prevent strains in the glass being produced by unequal contraction of the balsam Such strains are very likely to occur if the filters are dried too quickly or at unequal temperatures.

The danger of strain is much lessened by using glass of considerable thickness, and for this reason the larger filters are usually made in thick glass, while filters made from optical



(*a*) Original definition

(*b*) Definition after screwing up tightly in cell

FIG. 50. THE EFFECT OF STRAINING A FILTER

flats are no less than half an inch in thickness, so that no danger of strain remains.

After drying and cleaning, the filters are carefully tested for freedom from aberration, and are then ready for mounting in the fitting which is to carry them for use.

Here also care must be taken that pressure, and especially uneven pressure, is not put upon the filter in mounting. Filters are frequently fastened into cells by means of a screw clamping ring, and, if this ring has not a shoulder upon it, it is sometimes screwed tight down on to the filter in order to hold it tightly. Such a procedure is almost certain to distort a thin filter and spoil the definition, as is shown in fig. 50, where (*a*)

shows the original definition given by the filter and (*b*) that obtained after screwing the filter up in its cell.

The same defect may be induced by binding up the filters at the edge with strips of gum paper such as lantern binding strip. Even a label which extends over both glasses of a thin filter may cause sufficient distortion to make the filter very inferior.

The tests through which filters pass for optical definition are graduated according to the class of filter.

The Wratten test for Class A filters, cemented in optical flats, requires that the finished filter shall in no way degrade the definition of the test lens (of five feet focal length) when used at full aperture. Now this lens is specially designed to give the best possible definition, and the test object for flats contains a number of fine lines which are separated from each other only $\frac{1}{2000}$ inch. So that the test requires that a flat filter when used on a lens of sixty inches focal length at full aperture (about $2\frac{1}{2}$ inches) shall clearly separate lines only $\frac{1}{2000}$ inch apart.

This test may seem more accurate than is necessary, but by it one can guarantee flat filters to give perfect definition under any circumstances, even in high power telephoto work, or when used upon large lenses covering big plates for severely critical work.

Ordinary filters cemented in optical glass of good quality, but not in specially surfaced flats, are tested in a less severe manner. The test object for such filters is shown in fig. 51. This test object consists of a number of opaque lines crossing each other so as to leave transparent squares. In the instrument the image which is produced has lines $\frac{1}{60}$ inch across, fig. 51 being a photograph of the image enlarged about 17 diameters.

Fig. 52 shows the effect on the image produced by a filter showing slight astigmatism. In fig. 53 (*a*) and (*b*) a filter has been used in which the astigmatism is very severe.

If a filter shows astigmatism the set of black lines running in one direction will have a focus in a different plane to the set of lines running at right angles to them, so that one set must always be out of focus; in the case of bad astigmatism it is possible that one set of lines will disappear entirely when the other set are focused sharply, so that in Fig. 53 (*a*) shows one set of lines in focus, and (*b*) those at right angles to them.

We require of filters in B glass that at full aperture the

image shall be free from astigmatism and that the definition shall be such that filters up to two inches in diameter shall not visibly degrade the definition of a lens of six inches focus used at F 4.5. Filters between two inches and three inches in

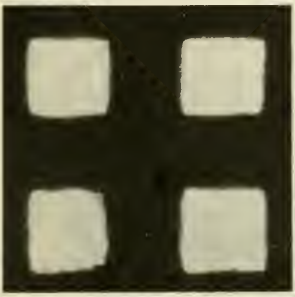


FIG. 51. FILTER-TEST OBJECT

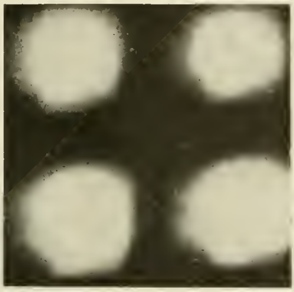
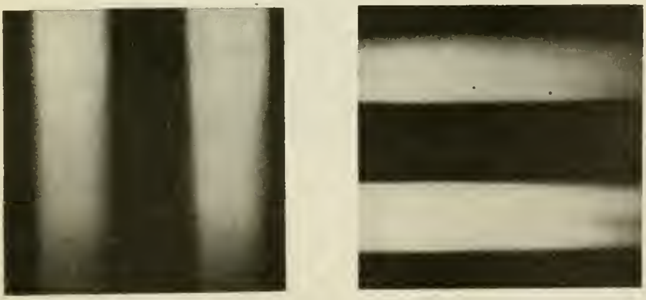


FIG. 52. TEST OBJECT THROUGH ASTIGMATIC FILTER

diameter must give good definition on a lens of ten inches focus used at F 4.5, while filters above three inches in diameter must give good definition on a lens of sixteen inches focus used at F 8.

For very long focus, or telephoto lenses, only flats will give satisfactory results, and for the semi-telephoto lenses, now



(*a*) FIG. 53 (*b*)

being introduced, it is also desirable that filters should be cemented in glass of the highest quality.

On stopping down the definition given by the filter should improve as the aperture is diminished.

In addition to giving satisfactory definition it is necessary that a filter should not alter the focus when it is used upon a lens. A camera should always be focused with the filter in position, but the use of focusing scales upon many small cameras renders it necessary that filters for hand camera use should not affect the focal plane of the lens. A filter can alter the distance between the lens and its focal plane in two ways, it may act as a weak supplementary lens, or it may, if behind the lens, produce an effect due to its thickness.

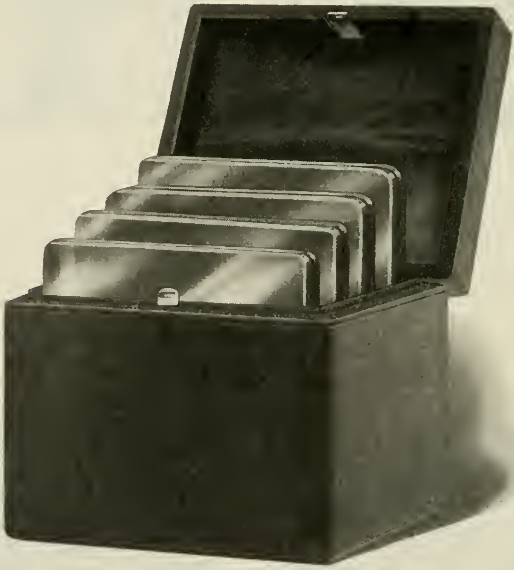


Fig. 54. Set of Tricolor Filters With Fourth Printer, Cemented in Flats

A "K" filter is tested not to affect the focal plane of a six inch lens by a greater amount than $\frac{1}{50}$ inch when used on the front of the lens. If a filter is used behind the lens, the lens must be moved back by an amount equal to about one-third of the thickness of the filter, but this rule assumes that the filter does not act in any way as a lens, and it is probable that some filters, which have been noted as not corresponding to the rule, really acted to some extent as lenses.

Besides the test for definition, which we have described, a set of filters, such as tricolor filters, which are to work together, must be tested for another optical requirement. They must give images of the same size, so that they will register when printed one upon another.

It is obvious that if the filters are used behind the lens, or even if they are used in front of the lens and the object be near the lens (as in ordinary picture copying or process work), that the filters must all be of the same thickness, and that the shorter the focal length of the lens the greater the error in register (for the same size of image) which a difference in thickness will introduce.

For some time it was thought that equal thickness was the main necessity for register, but with the utilization of the large filter testing instrument it was shown that filters vary also in their effect upon the focal length of the lens, it appeared that a complete theoretical and practical investigation of the optical conditions governing register was desirable.

In order to measure the accuracy of registration, an instrument was constructed in which a lens of about ten inches focal length formed images eight inches apart of two sharply defined sets of lines, and the exact distance between these sets of lines could be measured by means of two microscopes mounted on carriages actuated by micrometer screws.

Filters can be placed in front of the lens and the effect of these filters upon the size of the images can then be measured very accurately.

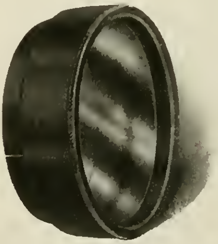
The tests upon this instrument have completely confirmed the theoretical sizes calculated from the known laws of geometrical optics, and the information which has been obtained is of considerable use in ensuring that sets of tricolor filters will give satisfactory register, while tricolor filters cemented in flats ("A" glass filters) can be guaranteed to show perfect register under even the most trying conditions.

All filters issued by the Eastman Kodak Company are tested on the two instruments described for definition, accuracy of focus, and, in the case of tricolor filters, for register.

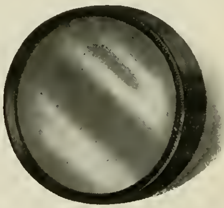
CHAPTER XII

THE FITTING OF FILTERS

FILTERS can be fitted either before or behind the lens, or just in front of the plate in a repeating back or special dark slide. This last position has the advantage that glass of lower optical quality can be used, but much larger filters are required and any speck or mark upon the filter shows in every negative, so that for orthochromatic filters a lens fitting is certainly to be preferred. Such filters should preferably be fitted in front of the lens, as in this position no appreciable



For Flats



For Filters in "B" Glass

FIG. 55. SLIP-ON CELLS

shift of focus is introduced by the thickness of the glass, and the filters are also more readily accessible.

Film filters may be conveniently placed between the lens components, but this cannot be done with cemented filters, because the introduction of a piece of glass would seriously affect the corrections of many lenses; even gelatine film should not be put inside an air-space lens, which, owing to its construction, is sensitive to small alterations in the air spaces.

A filter cell should always be designed so that the filter is held securely but without pressure, and if the filter is fastened in place by a screw ring this ring should have a shoulder and should be turned down, so that when it is screwed home the filter can easily be turned round by holding it between the thumb and finger, but will not give any side shake.

A method of fitting is to have the filter mounted in a light metal cell, which is slipped on to the lens like a lens cap (see fig. 55). This method of fitting has the advantage that the filter can be readily removed or changed.

When ordering a filter for this form of fitting it is only necessary to send the outside measurement of the lens, but it is necessary that this measurement should be made very exactly. If a pair of sliding callipers cannot be obtained a strip of hard writing paper should be wrapped round the lens

Fig. 56. Cutting a Slip of Paper to Fit a Lens

so that the ends *overlap*, and then the two pieces of paper, where they just overlap, should be cut through in position with a sharp knife (see fig. 56). An attempt to cut a strip of paper which will just go round the lens is unlikely to result in a measurement sufficiently accurate to ensure a well-fitting cell.

When slip-on metal cells are used there is some danger of pulling the cell off if a lens cap be used over it, but such a cap is unnecessary if a between-lens shutter be used.

Filters may also be fitted into velvet covered plugs to go inside lens hoods, so that the usual lens cap can be used.

In order that the same filter may be used on different lenses

adjustable holders are supplied for 2-inch square filters to go on lenses of $\frac{7}{8}$ to $1\frac{9}{16}$-inch diameter (fig. 57).

For 3-inch square filters. To fit lens mounts $1\frac{3}{8}$ to $2\frac{3}{8}$-inch diameter.

For 4-inch square filters. To fit lens mounts 3 to $3\frac{7}{8}$-inch diameter.

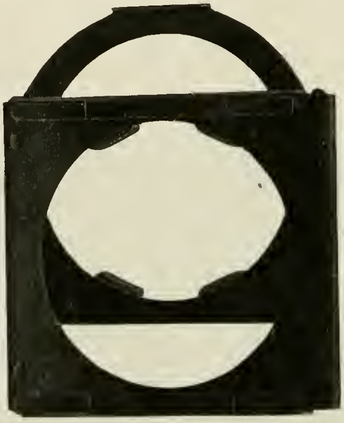


FIG. 57. EASTMAN ADJUSTABLE FILTER HOLDER

With filters cemented in flats it is necessary that the filter should be wider than the front lens component, because otherwise the filter, being of considerable thickness, will tend to cut down the angular aperture of the lens. The additional width necessitated can be found approximately in the following manner (see fig. 58): On a piece of paper draw a line equal to the focal

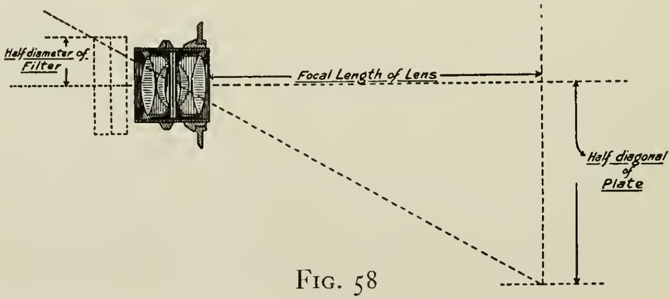


FIG. 58

length of the lens, at right angles to this draw a line equal to half the diagonal of the plate with which the lens is used. Now extend the first line for a distance equal to the distance from the diaphragm to the edge of the hood of the lens plus three-quarters of an inch, and at right angles to this draw another line. If now we join our starting point to the end of the line representing the diagonal of the plate, and produce this until it cuts the last line drawn, the length of that line which it cuts off represents half the necessary width of the filter.

Since filters in flats must be wider than the lens with which they are to be used, they should be fitted in special out-built cells which may be slipped on to the lens barrel (see fig. 55).

In order that there should be no mistake when ordering filters in "A" glass (flats) the following particulars should be given:

1. The name of the lens.
2. The focal length.
3. Maximum working aperture.
4. Length and diameter of lens barrel, over all.
5. Size of plate used.
6. If used for other than ordinary infinity work give average extension of camera.

Sets of tricolor filters, if small, are best fitted in a repeating back, and used with a dark slide carrying long plates; the three negatives being taken side by side on the same plate. Where larger sizes are required, or where it is not desired to use plates of special sizes, the filters may be fitted in a frame which can slide behind the lens through an outside protecting cover screwed to the lens panel, thus changing the filters somewhat in the manner in which lantern slides are changed by a lantern slide carrier. Although this method is rather slow in changing— as the dark slide must be changed as well as the filter—it is in other respects a satisfactory fitting.

It is also possible to make a holder, either of metal or of wood, to fit on to the lens, into which the three filters can be slipped in turn; this holder can also be used for any other filters in addition to the tricolor set.

For process cameras special holders for filters are advisable, and one holder in which each filter is put in place separately is probably the most satisfactory. In such work great care is

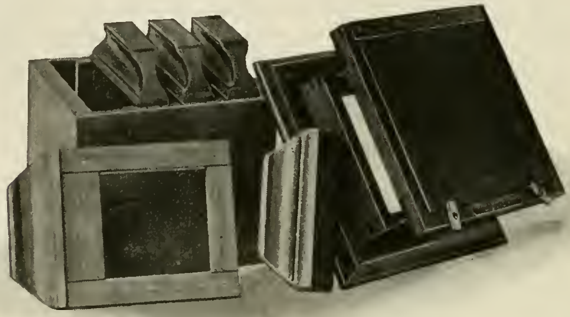


Fig. 59. Standard Frames, Holders and Box for Process Cameras.

necessary that each filter is put in the same place, and exactly square to the lens. One way up may be better than another, and all Wratten three-color filters are marked to show the best way to insert the filter into the holder.

CHAPTER XIII

THE CARE OF FILTERS

IN its simplest form (gelatine film) a filter requires a considerable amount of care in handling. The safest way is to place it between the combinations of a lens and leave it there. If it be used in front of or behind the lens in any form of carrier it should be removed after use and placed, in clean paper, between the leaves of a book, where it will keep flat and dry. Moisture tends to cloud gelatine film filters. The fingers are almost invariably moist and, to a certain extent, greasy, hence in handling gelatine films care should be exercised to hold them by the extreme corner, if the filters be square, or, better still, by the edges only.

If it be necessary to cut the film it should be placed between two clean pieces of fairly stiff paper, note-paper for instance, and cut with a sharp pair of scissors. A knife can also be used if the film is firmly held between two pieces of glass and trimmed round, taking care to cut and not simply to pull with the knife, as the film very easily splinters and cracks.

A film filter may be dusted with a piece of soft silk, or perhaps a better plan is to use the edge of a piece of very fine tissue paper. The latter will not scratch if used carefully, and does not leave any fluff on the film.

Cemented filters should be treated with care equal to that accorded to lenses, they should be kept in their cases and on no account allowed to get damp or dirty. Filters are clean when first sent out by the makers, and with reasonable care in handling they should never become so dirty as to require other cleaning than can be given by breathing upon them, and polishing with a piece of silk or tissue paper. A filter should never be washed with water, under any circumstances, because if water comes into contact with the gelatine at the edges of the filter it will cause it to swell and so separate the glasses, causing air to run in between the gelatine and the glass. Even if the swelling does not cause air to run in in this manner, the filter will be strained and the definition spoiled.

If for any reason the filter gets so dirty that it cannot be cleaned by simple rubbing, after breathing on it, a piece of fine tissue paper should be damped with denatured alcohol and gently rubbed over the surface of the filter. Care must be taken that the tissue paper is not wet enough for the alcohol to run out and spread over the edge of the filter, as it is a solvent of the balsam with which filters are cemented, and will soften it so that air may run in. Before attempting to clean a filter at all it is well to make sure that both the surface of the glass and the material are entirely free from grit, which will scratch the glass. If the glass becomes badly scratched the only thing to do is to recement the filter with the scratch inside, which can be done in the case of flats, although this involves a considerable delay while the recemented filter is drying.

In addition to moisture, undue heat is dangerous to filters, as it softens the balsam and causes the gelatine to contract, so that filters should always be protected from heat, as far as possible.

The dyes used for most filters are quite stable to light, a table showing the stability to light of all the Wratten filters being published in "Wratten Light Filters."

The "K" filters are particularly stable, and no fear of fading need be felt. Filters, however, should always be kept in their cases when not required for use; tricolor filters, especially, should be put back into the cases as they are taken from the camera in turn, they are then quite safe and can be always found when required.

The Aesculine filters, used for the removal of ultra-violet light in photographing drawings which contain Chinese white, must be protected from light, to which they are unstable, going brown when exposed to it for any length of time.

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